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NOVEL AMERICAN CLIMATIC MAPS AND THEIR IMPLICATIONS

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Analysis is here attempted in two chief ways of data accumulated during the 40 years 1899–1938 at about 5,000 American Weather Bureau stations. Many of these data were mapped, under the direction of J. B. Kincer of the Weather Bureau, in the 1941 Yearbook of Agriculture, "Climate and Man." Numerous regional correspondences and contrasts between various of these mapped data and of others partly derived therefrom are here pointed out, with the help of original maps. The climatological problems of the regional differences disclosed by the maps are briefly discussed.

The Kincer maps and those here given afford a more adequate basis for several sorts of climatological discussion than was available to earlier workers on the climate of the United States.

LOW TEMPERATURES

Map 1 shows that in a narrow southern zone the average January temperatures are about 50°, the mean minima about 20°, the absolute minima about 0°, and the average frost penetration is about 1 inch. These four isolines show that the influence of the Atlantic is less evident upon average January temperature than upon the others. The influence of the Pacific is conspicuous, as the isotherms for mean minima and absolute minima which cross northwestern Florida also cross western Washington and Oregon. The northwestern region has, however, distinctly lower average January temperatures than prevail in northern Florida.

In the middle zone of map 1, the associated isotherms are those of 30° (average January), 0° (mean minima), −20° (absolute minima), and 10 inches of frost penetration. Thus the temperature gaps or spread are about the same as in the southern zone, about 50° between January and the absolute minima, and about 30° between average and mean minima.

The effects of the Pacific Ocean and of the Great Lakes in interfering with low temperatures is made conspicuous by the northern isolines of figure 1. The coldest large area in the United States in winter is between the Rocky Mountains and Lake Superior. In most of that region, mean January temperatures are below 10°, mean minima below −30°, absolute minima below −50° and frost penetration ranges from 35 to 70 inches. The isotherms of that region correspond much less closely than in the other zones of this map: minima are relatively lower at the west than at the east, absolute minima notably lower in Wyoming than in Minnesota, and the gap or spread between the annual minima and the January average is relatively greater in Montana than in Wisconsin. This is partly a result of the higher elevation at the west, and partly because of the lesser atmospheric humidity in cold weather. The lowest average January temperature is, however, experienced in an area less than 1,000 feet above sea level, in the Red River Valley Basin. On the other hand, the absolute minima (at stations with long records) are at 2,000 feet (−63° at Poplar, Mont., in the Missouri River Valley), at about 5,000 feet (−60° in the Gallatin Valley of Montana), and at 6,690 feet (−66° at west Yellowstone Park). These are all inversion centers.

Another irregularity shown by the northern zone of map 1 is in average depth of freezing, which is distinctly less at the west than at the east, with corresponding temperatures. This is despite the fact that average snowfall increases eastward from Montana, and snow-cover protects the soil from deep freezing. In the three areas where −60° has been recorded, average frost penetration is only about 35 inches, in contrast with about 70 inches in northern Maine and in southern Minnesota, where minima are about −40°. The drier western soil is a better nonconductor than is the moister eastern soil, partly because dry soil does not crack so deeply in cold weather.

Map 2 shows regional contrasts in the difference between mean January temperatures and mean annual minima. For most of the country the difference is approximately 40°; in the Great Lakes and coastal region it is however, distinctly less than 40°, and in a northern Great Plains area it is from 45° to 50°. On the seacoast it is about 30° on the Atlantic and Gulf, and 20° on the Pacific. This map shows, therefore, in another way, that the continent's interior cools in cold weather relatively sharply, as compared with the average for January.

HIGH TEMPERATURES

The isotherms for average July air and wet-bulb temperatures, and for average and absolute maxima, follow such irregular courses that there are no distinct zones on a map showing all four sets of isotherms. Hence map 3 shows only isotherms of average July air and wet-bulb temperatures. It shows that July wet-bulb temperatures are about 75° near the Gulf, between 60° and 65° in most of the North, and about 55°–60° in most of the West. July air temperatures average between 80° and 85° in the South, about 70° in the North, and 60°–70° in the West. Map 4, showing the average difference between July wet-bulb and air temperatures, reveals that in the arid Southwest, wet-bulb temperatures are 15°–20° below air temperatures; but along the Pacific coast, in the Northeast, and in part of the North, the difference is less than 5°. The gap is about the same in the Southeast as in Wisconsin, but the higher air temperatures in the Southeast makes the sensible temperature more trying. For most people, under usual shade conditions, a wet-bulb temperature of 60° is not hot, while one of 70° is trying, and one of 75° distinctly enervating. Despite their far higher average air temperatures, northern Arizona and New Mexico have lower wet-bulb temperatures than have even Maine and the upper peninsula of Michigan. At Yuma, Ariz., however, the average July air temperature is so high (92°) that the average July wet-bulb temperature is as high as in northern Georgia and at Norfolk, Va.

The maps of average and absolute maxima show so little latitudinal or regular longitudinal contrast (despite a range in the United States of more than 25° for the average maxima and more than 30° for the absolute maxima) that the map made by superimposing the two sets of isotherms is not published here. Instead, some of the revelations are briefly described.

There is only slight average latitudinal contrast in annual maxima, an average difference of only about 5° between the southern and northern margins of the country. East of the 100th meridian, the average annual maxima along the Canadian border are about 94°, along the Gulf of Mexico about 98°. Midway between, the average annual maxima are about 100°, except in the Great Plains States where they are about 105°. The coolest northern areas are the North Pacific coast (where the average is about 85°), northwestern Maine (where the average is not quite 90°), and near the Great Lakes (where it is about 95°). Along the southern border, the average annual maxima are only 95° at Miami, Fla., are somewhat less than 100° along the Gulf coast, are about 105° along most of the Mexican border, but are 115° in a sizable southwestern area to the north of Yuma.

Comparison of the absolute and annual maxima reveals that most of the country has had maxima only 5° to 10° higher than the mean annual maxima. This difference is only a fourth to a ninth that between the annual and extreme minima (map 2). The map, not here reproduced, showing the spread between mean annual and absolute maxima shows that west to about longitude 85°, the spread is about 5°, except in northern New England where it is 10°; in the Midwest, it is 10°–15°, in the Southwest about 10°, and in the rest of the country, from 3°–9°.

The hottest minute of an average year is almost as hot as the hottest minute of 40 years, chiefly because at the high temperatures attained, radiation is so rapid as to interfere seriously with the attainment of higher temperatures. (According to the Stefan-Baltzmann law, a black body loses heat by radiation proportionately to the fourth power of its absolute temperature.) Significant also is the fact that when most intense, solar heating is soon checked by decline in the height of the sun, and often by convectional clouding.

A map of the spread between annual and extreme minima, which corresponds to the map just described, may be briefly described. It shows that in most of the country, the absolute minima were 15°–20° lower than the annual minima. The spread was less than 10° only along the Pacific coast, in southern Texas and Florida, in New York and locally near the Great Lakes. It was 25° or more in two areas, one extending from southern Montana to Nevada, and a small one centering in northern South Carolina.

The fact that the downward spread between mean and extreme minima averages two or three times as great as the upward spread between mean and extreme maxima shows that deficiency of heat is easier to attain than excess. The almost negligible effect of the Gulf and of the Atlantic is the most notable because of the conspicuous influence of the Pacific Ocean. The fact that downward departure is greater in the Southeast than in the Northeast reflects the rareness of intense cold in the former area, a result of the fact that polar air masses usually get warmed before reaching the Southeast.

Figure 5 maps the spread between the July average temperature and the mean annual maxima. It shows an increase from the Gulf coast northward and also northwestward, almost to the Pacific. In a sizable northwestern zone the spread is almost twice as great as near the Gulf. For most of the country it is about two-thirds as great as the spread between the January mean and mean minima (map 2). Comparison of maps 2 and 5 discloses lessened significance of the Pacific Ocean in map 5 and radical differences as to the Great Lakes. The relative highness of July mean maxima in the West than in the Southeast reflects humidity contrasts. The average increase with latitude accompanies the increase in length of day.

Absolute maxima are higher in northern Maine than in southern Florida, in northern North Dakota than in southern Texas, and in central Washington than in southwestern California. This is partly because at the summer solstice the day is 2 hours longer in latitude 49° than in latitude 30°. Significant also is the proximity of the ocean to these southern areas but not to these northern ones. Moreover midday cloudiness and showers are more frequent in the South than in the North.

Likewise, of some significance, is the greater width of the continent at the north than at the south, and generally southwesterly winds in hot weather.

The average absolute maxima are about 100° both along the Gulf coast and along the Canadian border east of Minnesota; they are approximately 105° for most of the remainder of the East except an area extending from Indiana to Louisiana, where 110° to 118° have occurred. A zone extending from North Dakota and Montana to southern Texas has had 110° to 120°, as have the arid areas in eastern California and central Washington. Absolute maxima below 100° have prevailed, however, in a large western elevated area extending from western Montana to New Mexico.

For stations having long records, the extreme maxima were 134° in Death Valley, Calif., 130° in the Imperial Valley, Calif., and 127° at two Arizona stations, all four in true deserts. The absolute maxima in some normally semiarid or humid areas are also high. Examples are 121° in Kansas, 117° in northern Montana, 116° in northern Indiana, 111° in Pennsylvania, 106° in Maine. These places were all abnormally dry, however, at the time these records were established.

ANNUAL RANGE OF TEMPERATURE

The next three maps show temperature ranges of three magnitudes. Figure 6 shows that in much of the North, July averages about 50°–60° warmer than January but that near the Gulf and the Pacific the difference is only 20°–30°. The greatest range is near the continent's center, but the effect of the Atlantic and of the Great Lakes is not prominent.

Map 7, the range between mean maxima and minima, shows contrasts near the Pacific and Gulf three times as large as those of map 6, and in the interior of the continent somewhat more than twice the contrast. The effect of the Atlantic and the Great Lakes hence is more pronounced;

the latter influence helps to explain the westward shift of the area of greatest range.

Map 8, the absolute range (during 40 years) shows that almost everywhere except on the immediate Pacific and Gulf and southern Atlantic coasts the range has been more than 100°, for most of the country it has been more than 130°, in the northern Great Plains, more than 160°. This most extreme area is somewhat further west than the corresponding parts of maps 6 and 7.

Although in the central longitudes (95°–110°), there is a rather steady northward increase in range, the northward increase is broken in the eastern half of the country by the Great Lakes, parts of which area has no more extreme range than does central Texas. Near the Pacific cost the latitudinal effect is lacking; instead, a sharp increase occurs with increasing distance from the ocean.

Map 9 shows the spread or difference between the annual normal range (fig. 6) and the extreme range (fig. 8). It shows that the Pacific coastal zone occasionally has greater departures from normal than is true for most of the country. Occasionally the moderating influence of the ocean is overcome by winds off the continent. The relatively large contrasts shown for part of the Southeast reflect rare exceptionally cold air masses, or exceptional drouth, permitting abnormal heating or cooling.

State extreme ranges are of sufficient interest to justify a summary. Both Montana and Wyoming have State ranges, among stations with long records, of 180° (from −63° to 117°; −66° to 114°); for New York, the range is 160° (−52° to 108°); for Indiana, 149° (−33° to 116°); for Tennessee, 145° (−32° to 113°); for Georgia, 123° (−12° to 111°); even for Florida the range is 111° (−2° to 109°). For California, partly because of contrast in elevation, latitude, and proximity to the ocean, the range is 170° (−36° to 134°); for Utah it is 166° (−50° to 116°); for Arizona and Washington it is 160° (−33° to 127°; −42° to 118°).

ANNUAL PRECIPITATION

The next 6 maps present data as to annual precipitation. The aim of this series is to discover facts as to the variation between wet and dry years, the regional contrasts therein, and something as to causes.

Map 10 superimposes selected isohyets for "relatively wet" and "relatively dry" years. (Whenever "relatively dry" is used here, it connotes a year so dry that only one-eighth of the years receive less precipitation than that shown for the dry year. Conversely "relatively wet" signifies that only one-eighth of the years receive more than that shown for the wet year.) This map shows five vague belts east of the Rocky Mountains in which isohyets are rather close together. Consequently it indicates the amount of the range from wet to dry reasonably to be expected in many areas. For example, in a zone extending from Maine to southeastern Kansas and thence due south to the Gulf, the total in a relatively wet year is about 50 inches, in a relatively dry year about 30 inches.

The precipitation contrast or spread between relatively wet and relatively dry years is shown in map 11. This map shows that the difference is greatest in the southern Appalachians and near the Gulf of Mexico, where it is more than 30 inches. It is 25–30 inches on the North Pacific coast. For most of the Northeast it is approximately 15 inches, and for most of the northwest quarter less than 10 inches.

Map 11 shows that the absolute precipitation range decreases roughly with annual precipitation, but at a slower rate in the Southeast than in the rainy Northwest, where the orographic influence is pronounced.

Map 12 considers the relative or percentage variation between relatively wet and dry years. It has quite a different appearance than map 11, where the absolute variation is mapped. Map 12 shows that the part of the country with the least variable precipitation in three-fourths of the years is that bordering the eastern Great Lakes, where the variation is less than 30 percent of the annual average precipitation. In the Southwest, however, the range is 100 percent—as great as the annual average precipitation; part of it has a 300 percent variation. This map reveals a general southward increase in variability. Exceptions are the southern Appalachians, the northern Great Plains, and the Puget Sound, which have more variation than their surroundings. Conversely, some of the Rocky Mountains have less variability than nearby lowlands.

The variability of annual precipitation is illustrated in additional ways by maps 13 and 14. Map 13 shows that in a relatively wet year, the Mississippi Delta receives 20 inches more than normal while, conversely, most of New York receives only 3 inches more than normal. Map 14 shows that in a relatively dry year the Great Lakes region receives about 5 inches less precipitation than normal while the eastern Gulf coast receives 15 inches less. The deficiency is even greater in the southern Appalachians, while in the northern Pacific coastal zone more than 20 inches less is received in a relatively dry year than in a relatively wet year. Comparison of maps 13 and 14 shows that the plus (upward) and minus (downward) departures from normal are approximately equal in magnitude in most of the country but that the downward departure is relatively heavy in the wetter regions. This map brings out a seldom recognized point—that a relatively dry year in the North has a deficiency comparable to that occurring in much of the semiarid and arid West, while a relatively dry year in the South has two or three times as great a deficiency as has the North and the Northern Great Plains.

Map 15 shows that the percentage of the years having less than 15 inches of precipitation increases rapidly westward from about the 95th meridian, east of which no year is that dry, to the 105th–110th meridians, west of which 75–100 percent of the years are generally that dry. The two dashed lines on map 14 show the drier limits of the regions in which the annual totals are "always" above 20 inches.

Map 15 shows marked longitudinal influence, while latitudinal influences are indicated vaguely in both the eastern and western halves. The latitudinal influence in the East is associated with increased distance from the chief source of moisture, the Gulf of Mexico; that in the West is largely due to more effective cyclonic influence toward the north, which is in small part associated with the Columbia Gorge through the Cascade Range.

Maps 10–15 lend support to the generalization first deduced from other evidence as to the greater average variability of tropical than of mid-latitude climates.[1]

Maps 10–15 lend little support to the common generalization that precipitation is especially erratic in dry regions and is relatively dependable in humid regions. Instead, these data indicate that in the years here studied, the absolute difference decreased sharply in three-fourths of the years from humid to arid, and the percentage variation averaged about the same in arid, semiarid, and humid regions. Wet and dry years of notably more extreme types than are here studied occur, however, and

[1] S. S. Visher: Variability of Tropical Climates, *Meteorological Magazine* (London), vol. 58, 1923, pp. 21–26, 154–159, 178–180. Vergleichung der Niederslagsveranderlichkeit in Niedrigen und Mittleren Breiten, *Meteorol. Zeitschrift*, vol. 41, 1924, pp. 46–49.

it is these exceptionally wet and dry years that have given rise to the generalization that variation increases with aridity. In the wettest year of the half century 1889–1938 as compared with the driest year in that half century, State averages show that most of the western half of the country has somewhat more range than the eastern half (fig. 16). In most of the East, about twice as much precipitation was received in the wettest year as in the driest, while in the West the spread averages about 2.5-fold. It was, however, less than twofold in the three Northwestern States, and was nearly 50 percent greater in Virginia than in Oregon or Washington. In the Southwest it was nearly threefold; in Nevada (4.9″ vs. 14.1″), 3.5-fold in Arizona (7.8″ vs. 27.8″) and fourfold in California (10.4″ vs. 42.1″). It was least in the Northeast, slightly less than 1.5-fold in New England, New York, and Michigan, but was only slightly more in Florida (1.6). In the Great Plains it increased southward from North Dakota (2.5) to Texas (2.8).

Hence the regional increase in variability shown by map 16, of the spread between the driest and wettest years of a half century, is from north southward (except in a part of the East) and from the coast inland (except for the Southwest).

SEASONAL PRECIPITATION

The Yearbook maps of the average precipitation in each of the seasons of the year reveal conspicuous contrasts. In summer less than an inch is received in most of California, in contrast with a winter total of somewhat more than 6 inches in southern California and one of 20 to 30 inches in northern California. In Western Washington and Oregon, the seasonal range is from an average of about 4 inches in summer to an average of about 35 inches in winter. The Great Plains receives less than 2 inches in winter but 6 to 8 inches in the average summer.

It is less well known that Florida normally receives nearly three times as much rain in summer as in winter (about 22 inches compared with 8 inches). Much of Arizona also receives about three times as much in summer as in winter (6″ vs. 2″). The Great Basin Region receives in winter, however, about twice as much as in summer, but the totals are small (about 2 inches compared with about 1 inch).

The amount of precipitation in autumn is intermediate between summer and winter in much of the country. Autumn on the North Pacific coast resembles winter rather than summer, but the reverse is true in southern California and in Florida.

The precipitation totals in spring are generally intermediate between those of winter and summer; in Florida, however, the totals received in spring are only a little more than for winter and are less than half those for summer.

An analysis of the seasonal data mapped by Kincer discloses several hitherto unrecognized conditions and raises some challenging climatological problems.

Map 17 shows the location of areas of relatively heavy and relatively light precipitation in each season. The approximate superposition of these areas reveal their seasonal shifts. The southeastern area of heavy winter rainfall (centering in the State of Mississippi which receives 17 inches, or more than any other part of the country except western Washington and Oregon), is succeeded in spring by an area of about the same size and total precipitation, centering somewhat northwest of the center for winter. In summer, the area with more than 14 inches of precipitation is situated to the east of the winter and spring areas. To the northwest, however, is an area which receives 12 to 14 inches, appreciably more than the adjacent regions. It extends from western Wisconsin to Arkansas. In autumn, the area of relatively heavy precipitation is situated between, or overlapping, the areas of heavy winter and relatively heavy summer precipitation. It centers in southern Missouri, and receives 10 inches or more.

Conversely as to areas of little precipitation, map 17 shows a distinct southwestward seasonal shift. Least winter precipitation occurs in a broad longitudinal zone mostly in the Great Plains, where less than 2 inches of precipitation is received in the 3 months. In spring, the region receiving less than 2 inches is situated to the southwest of the dry winter belt. In summer, it is situated still farther southwest, including much of the Pacific States but not extending east to the Rockies. In autumn, the area receiving less than 2 inches is much smaller and largely limited to the Great Basin.

Map 17 shows that little more than the continually arid area (in Nevada and just south thereof), normally receives less than 2 inches of precipitation in more than 1 of the 4 seasons. Most of Nevada normally receives less than 2 inches in each season, which is also true of extreme eastern California and the adjacent part of Arizona.

The seasonal shiftings of precipitation are shown in another way by maps 18 and 19. Map 18, of the excess of summer precipitation over winter precipitation, or vice versa, shows that most of Florida has a summer excess of more than 10 inches, while an area larger than Florida, extending from Lake Superior to Kansas normally has one of 8 inches or more. About three-fourths of the country has a summer excess, but the Pacific coast and part of the lower Mississippi Basin have a winter excess. The winter excess is small in the latter region but in part of the Pacific coast it exceeds 20 inches. The winter excess in the South is largely due to heavy rains on stalled fronts.

Map 19 shows that spring and autumn receive approximately equal amounts of precipitation in most of the country, but autumn is distinctly the wetter season in southern Florida, while spring is the wetter in the Lower Mississippi Valley. The autumn excess in Florida is partly due to the presence of more autumn than spring tropical cyclones, some of which yield totals large enough to affect the averages for even 40 years. The autumn excess near the Great Lakes and to the east thereof is partly due to the comparative warmness of the Lakes in autumn. This favors the development of convectional disturbances, including thunderstorms, and leads to an intensification of cyclonic disturbances. In spring, when the Lakes are relatively cold (and parts of their shores are still snow-covered) these sorts of precipitation are decreased. The somewhat lesser spring than autumn precipitation in most of the western third of the country is partly attributable to lower average spring temperature associated with winter snowfall, some of which remains (at least on the mountains) until the spring is well advanced. This interferes with convectional precipitation, which, although much of the rain is of the frontal type, has some comparative significance. (This influence is partly offset by the greater orographic precipitation on the cold mountain sides in spring than in autumn, under similar wind conditions.) Most of California has more spring than autumn precipitation. This is chiefly due to the relative frequence of cyclones with fronts but conceivably is influenced indirectly by seasonal contrasts in soil moisture. In spring the soil retains some of the abundant moisture received in winter. In autumn, by contrast, the soil has been rendered dry by the almost rainless summer, with the result that condensation is interfered with.

The seasonal shifts indicated by maps 10–19 are closely related to changes in average temperatures and air pressure in the continental interior. In winter when the interior is relatively cold, not only are northwesterly winds common, but any northward moving air masses commonly encounter fronts, which they attempt to override, and are chilled relatively soon, and are compelled to drop their excess moisture in the South or middle East. In summer, conversely, the interior is relatively warm, inblowing winds are common except on the Pacific coast, and northward moving air masses are heated rather than cooled. The heavy summer rainfall close to the Gulf of Mexico and to the South Atlantic coast is largely due to stronger local convection, but in part reflects the significance of numerous tropical disturbances (few of which are hurricanes), many of which yield such heavy rainfalls within a few score miles of the ocean as to raise the average appreciably.[2]

The position of the eastern areas of relatively heavy precipitation also suggests a topographic influence. They are situated chiefly in three areas so far as elevation is concerned, (1) in the lowland between the southern Appalachians and the 1,000 feet contour at the west, (2) between the Gulf and the southern Appalachians, and (3) (as to the northern summer area) in the Ozarks and the more hilly parts of Iowa, the unglaciated part of Minnesota, and a morainic section of western Wisconsin. These latter areas favor thunderstorm development by inducing local turbulence, by lifting and by the heating of slopes.

The scanty summer rainfall in the Pacific States is partly due to the fact that the winds generally blow parallel to the coast, and the coast ranges interfere with the inward penetration of the moist air. Significant also is the fact that the land there is so much hotter than the Pacific Ocean in summer that any inblowing air has its relative humidity lowered and is able to retain its moisture. This retention helps prevent thunderstorms, the major cause of the summer rainfall of the East. Thunderstorms are also few in summer in the Pacific States because cyclonic disturbances are few then. They are few for two chief reasons; (1) the average course followed by mid-latitude lows in summer is across Canada, (2) far fewer tropical disturbances enter the Southwest than the Southeast.[3]

The contrasts between the rainfall totals received in relatively wet and relatively dry summers are shown in maps 20 and 21. The totals received are shown on map 20 by superimposed isohyets, while the spread between the totals received is shown on map 21. These maps show that in a relatively wet summer, New York receives about 18 inches, as does Iowa. In a dry summer, New York receives 6–8 inches and most of Iowa receives about 6 inches. Most of California receives about an inch on a wet summer, but none in a dry one. The spread between wet and dry summers (fig. 21) is more than 14 inches in parts of the Gulf and South Atlantic coast, is about 8 inches in most of the Northeast and Midwest and is less than 2 inches in much of the Southwest. Although the total received in a wet summer in the Southwest is distinctly small, it may interfere badly with the preparation of prunes, raisins and other dried fruit and may cause serious damage to some fruits which are not being dried, for example, by leading to the cracking of almost ripe cherries.

[2] Visher: Rainfalls of 10 Inches or More in 24 Hours in the United States, *Monthly Weather Rev.*, vol. 69, 1941, pp. 353–356; and Visher: Torrential Rains as a Serious Southern Handicap, *Geogr. Rev.* vol. 31, 1941, pp. 644–652.

[3] Visher: The Frequency of Tropical Cyclones, Especially Those of Minor Intensity, *Monthly Weather Rev.*, 58 (1930): 62–64. Effects of Tropical Cyclones upon the Weather of Mid-latitudes, *Geogr. Rev.* vol. 15, 1925, pp. 106–114.

Map 21 shows, as does map 11, that the absolute range increases with the precipitation. The magnitude of the range is almost as great as the local average summer rainfall in most of the country. In a large southwestern region (especially California), the range is somewhat greater than the normal summer total.

In the eastern half of the country, there is a large southward increase in absolute vairability and a distinct southward increase in relative variability, just as for the year as a whole (fig. 12).

One of the interesting features of map 21 is that the variability is notably greater in the southwestern part of the Corn Belt (Missouri, eastern Kansas) than it is in the northern part (southern Minnesota). In both of these areas it is approximately as great as the average precipitation; thus it is relatively great. Somewhat west of this Corn Belt area, in the northern Great Plains, the normal range is somewhat less, only about three-fourths of the average precipitation. But, as in arid regions, occasionally in semiarid regions there is very little rainfall during a summer. This fact gives the northern Great Plains region a bad reputation, not to be overcome by the fact that in three-fourths of the years its range is somewhat less than in most of the country.

THUNDERSTORMS AND HAIL

The frequency of thunderstorms is significant in explaining the differing amounts of summer rain and of hail. Comparison of maps 17 and 22 shows that, in general, the region where thunderstorms are relatively frequent have comparatively heavy summer rainfall, while most of the region which has few thunderstorms has light summer rainfall. The correspondence is less close than it would presumably be if summer rain were compared with summer thunderstorms instead of with all thunderstorms. For example, western Wisconsin, which has relatively heavy summer rainfall, has fewer thunderstorms according to map 22 than has southern Indiana, which has less rainfall. But many of southern Indiana's thunderstorms occur in spring and fall; during the summer, Wisconsin normally has several more thunderstorms than does southern Indiana.

Map 22 shows a Rocky Mountain region which has annually from 40 to 60 thunderstorms (nearly all of which occur in summer). That region, however, has little more recorded rain than the surrounding zone with fewer thunderstorms. This is partly because many Rocky Mountain thunderstorms yield little rain to the lowlands where most of the rain gages are located. The lightning of these mountain thunderstorms often set forest fires; they yield hail relatively often, but in that dry region hail is far less likely to disappear by melting in falling than is rain by evaporation.

Map 21 discloses that not far from the Pacific coast, 1 thunderstorm in 5 yields sufficient hail to cause damage; that in eastern Idaho 1 in 8 does, that in the central Great Plains, 1 in about 8 to 12 does; that in the western part of the Corn Belt, 1 in 10 to 15 does; in the eastern part of the Midwest, the ratio is 1 damaging hailstorm for 15 or 20 thunderstorms. In most of the Southeast, there is only 1 damaging hailstorm per 25 to 40 thunderstorms, while in Florida, with about 1 hailstorm a year and at least 70 thunderstorms, the ratio is less than a tenth that in most of California.

The eastward decrease in hailstorms as compared with thunderstorms reflects two chief influences, elevation and storm intensity. Most of the areas where hailstorms are relatively frequent are situated at altitudes of 4,000 to 7,000 feet above sea level, therefore much nearer the freezing atmospheric level. The Southeast, however, is near sea level, and doubtless much hail melts before reaching the ground. Note that near the mouth of the Colorado River, a western area near sea level, the ratio of hail to thunderstorms is 1 to more than 20, or far smaller than in most of the West, with its greater elevations. More hailstorms occur in the West than in the East also partly because western thunderstorms are on the average more violent, although they are briefer and yield less rain. Some eastern thunderstorms are as violent as any in the West, but most of them are not violent, partly because, as a result of the abundant moisture in the air, thunderstorms which are only moderately intense often can develop. Hence of 40 or 50 eastern thunderstorms a year, three-fourths may be of only moderate intensity. In much of the West, however, summer conditions are usually so unfavorable for condensation that the cloud base is relatively high, so that convection must be stronger, reach higher, than in the humid East to cause a thunderstorm. In other words, only relatively intense convectional disturbances can cause enough condensation in the dry West to liberate enough energy to create thunderstorms (by the splitting and fall of the raindrops). Such intense disturbances are the type which yield hail.[4]

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[4] Helpful suggestions were received concerning a preliminary manuscript edition from Charles F. Brooks, John K. Rose, and Robert G. Stone.

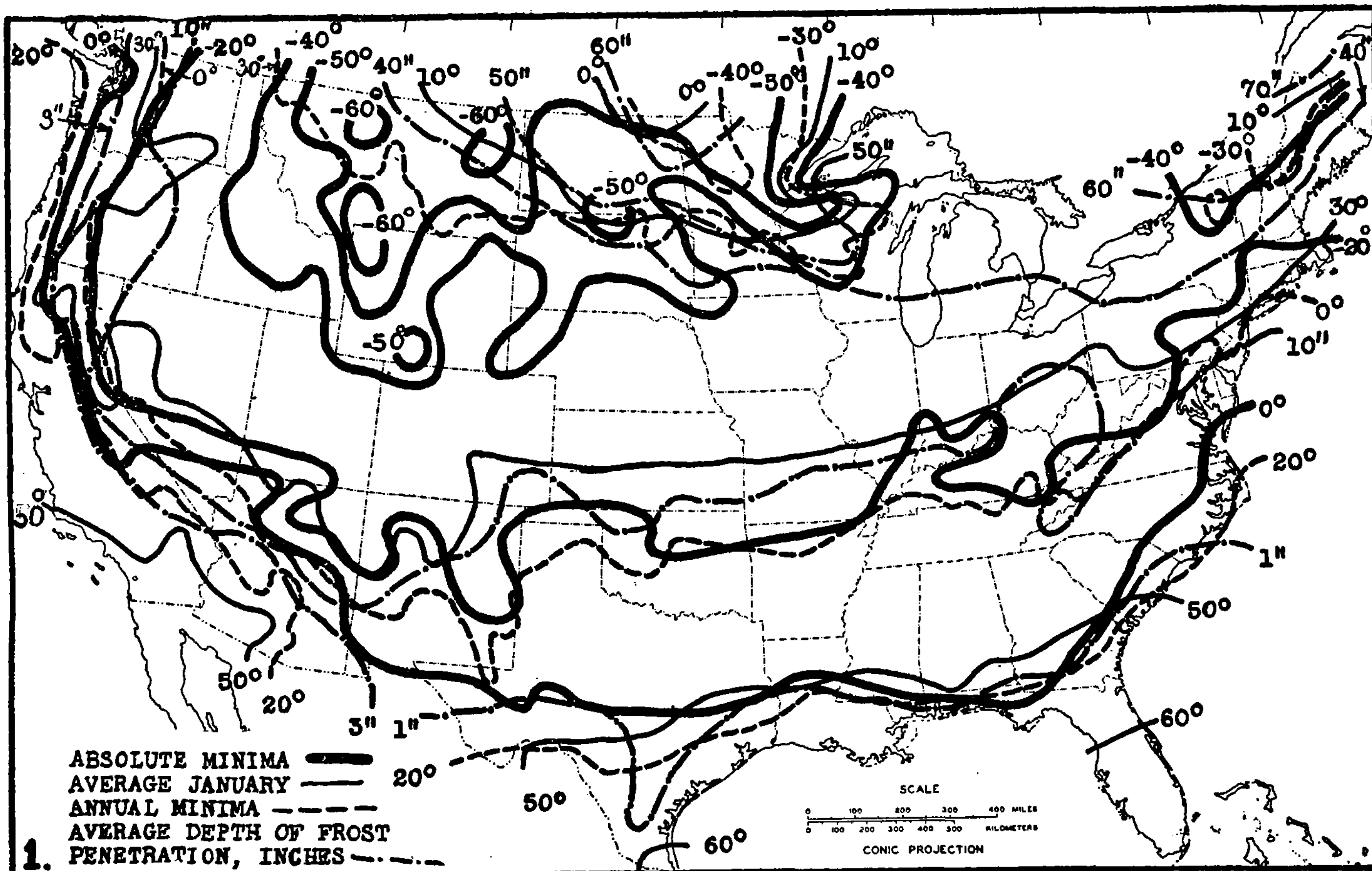

FIGURE 1.—Superimposed isotherms of average January temperatures, average minima and of extreme minima (° F.); also average depth of frost penetration (inches).

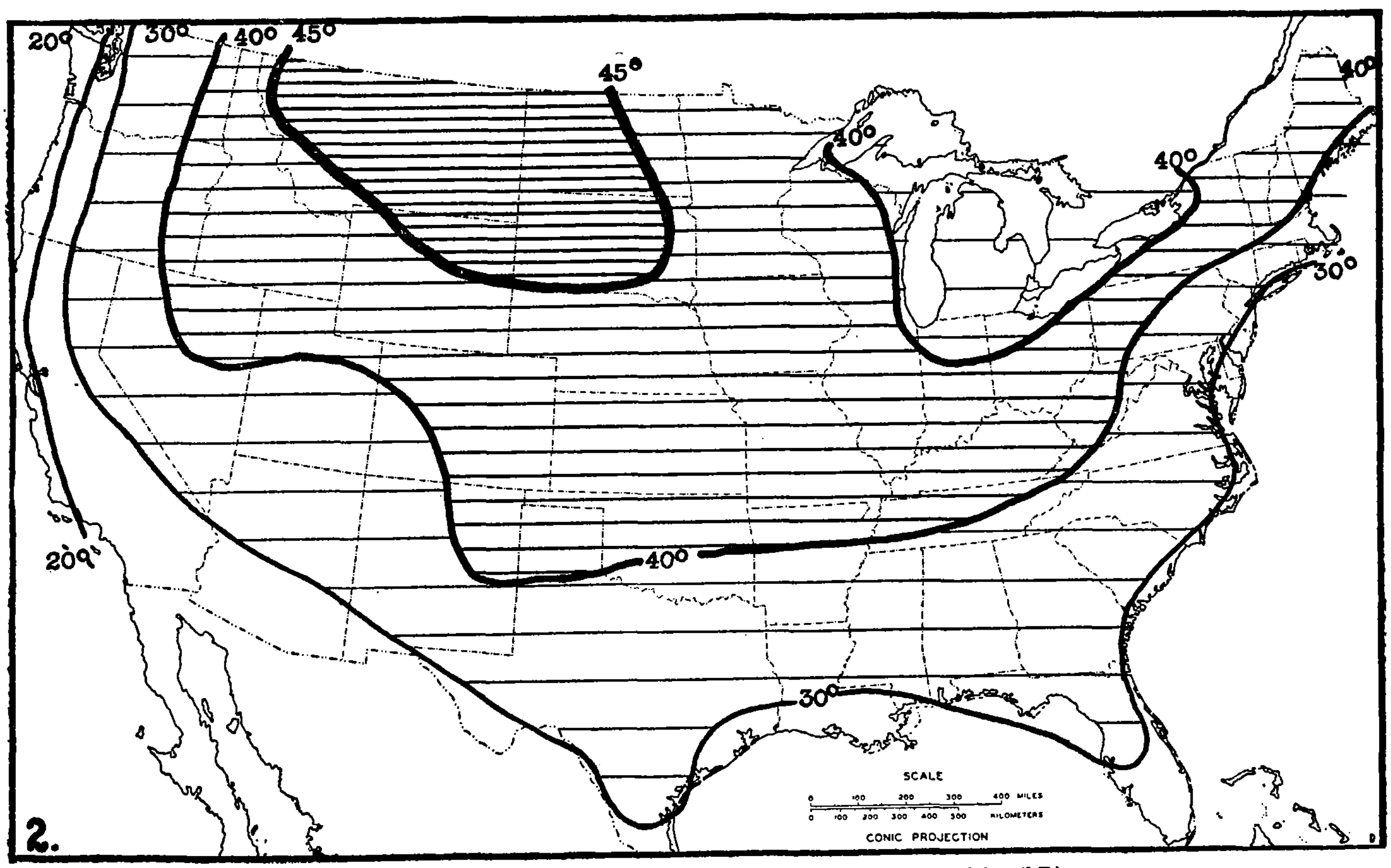

FIGURE 2.—Difference between mean January temperature and mean annual minima (° F.).

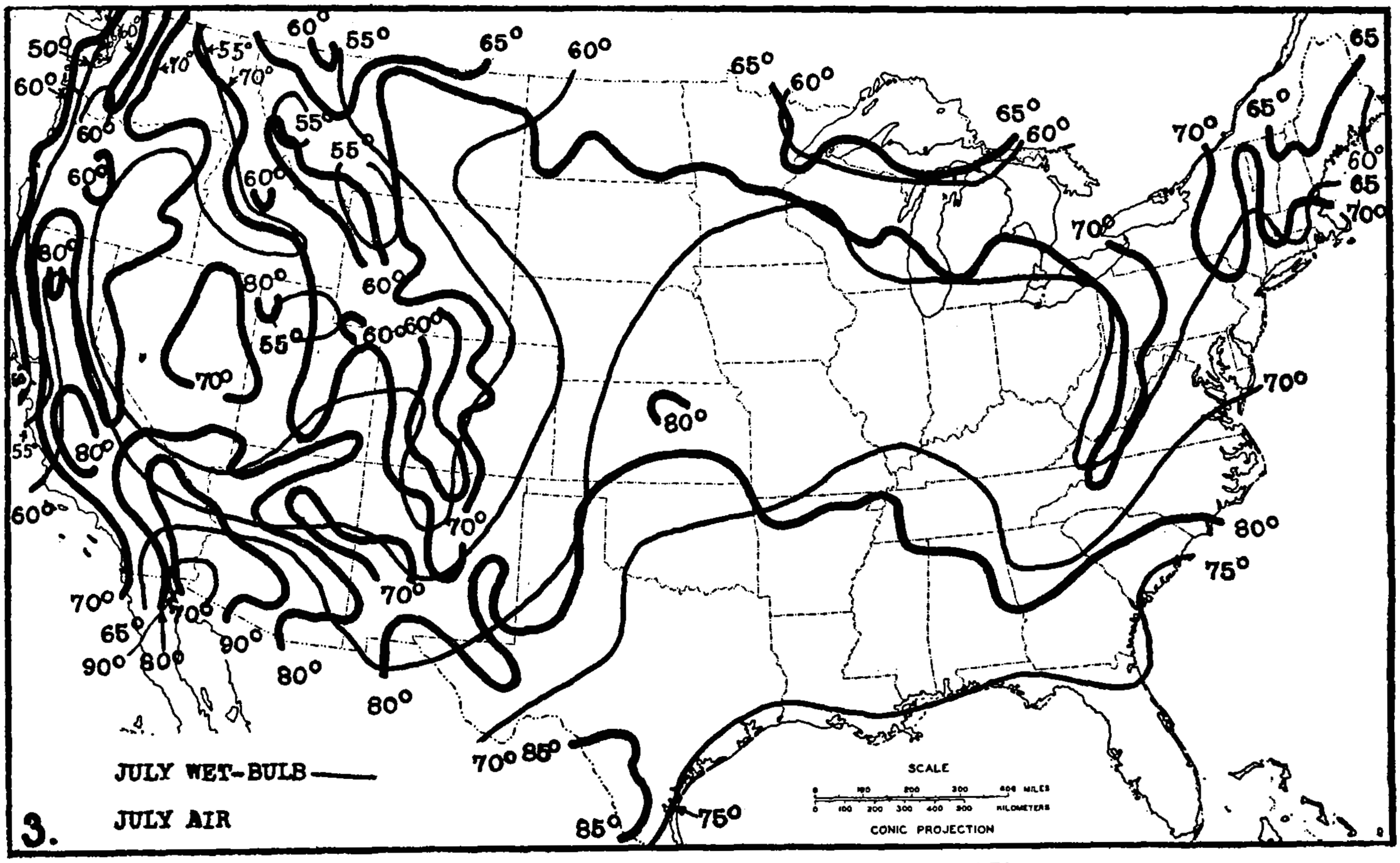

FIGURE 3.—Average July air and wet-bulb temperatures, selected isolines (° F.).

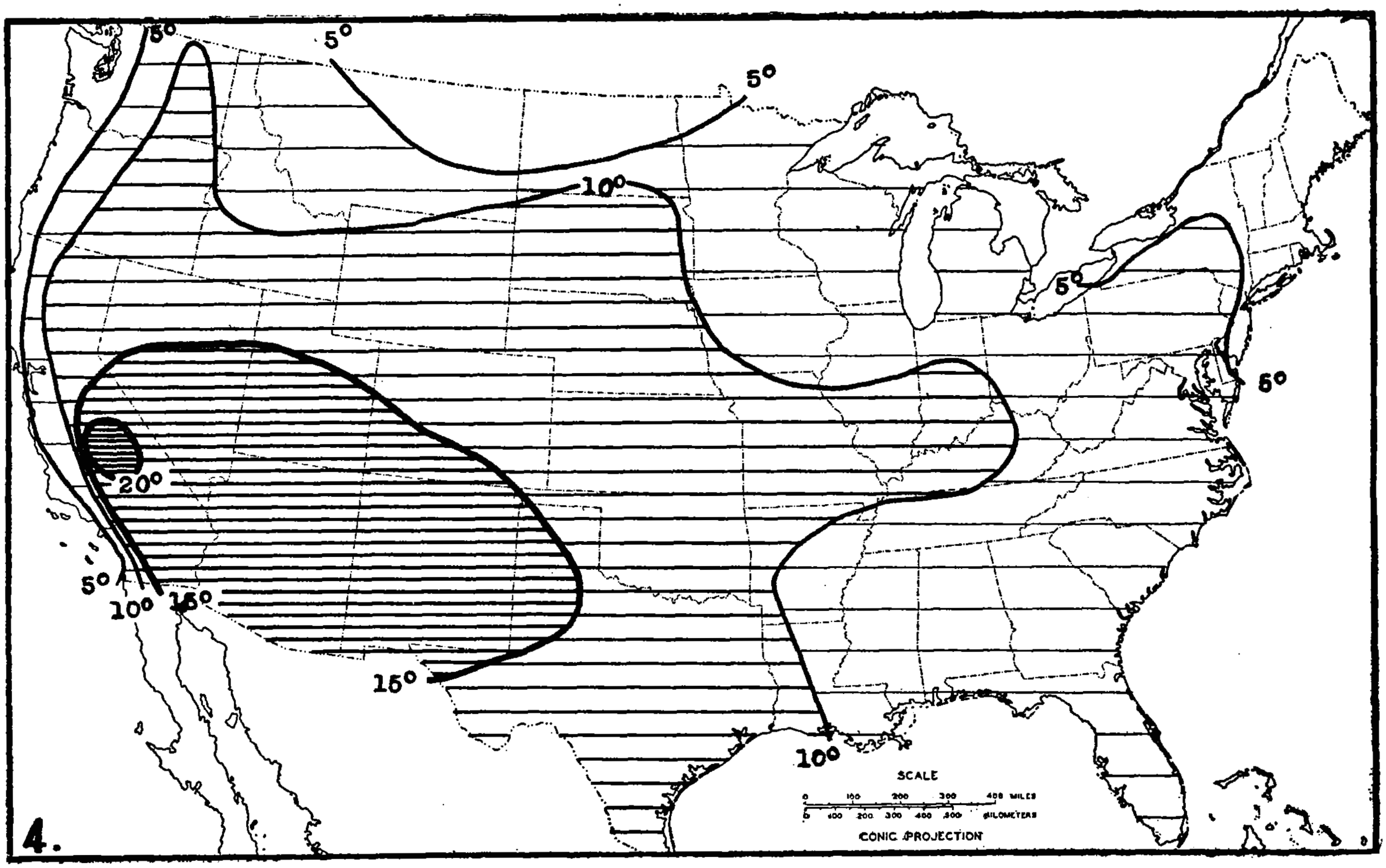

FIGURE 4.—Average differences between mean July air and wet-bulb temperatures (° F.).

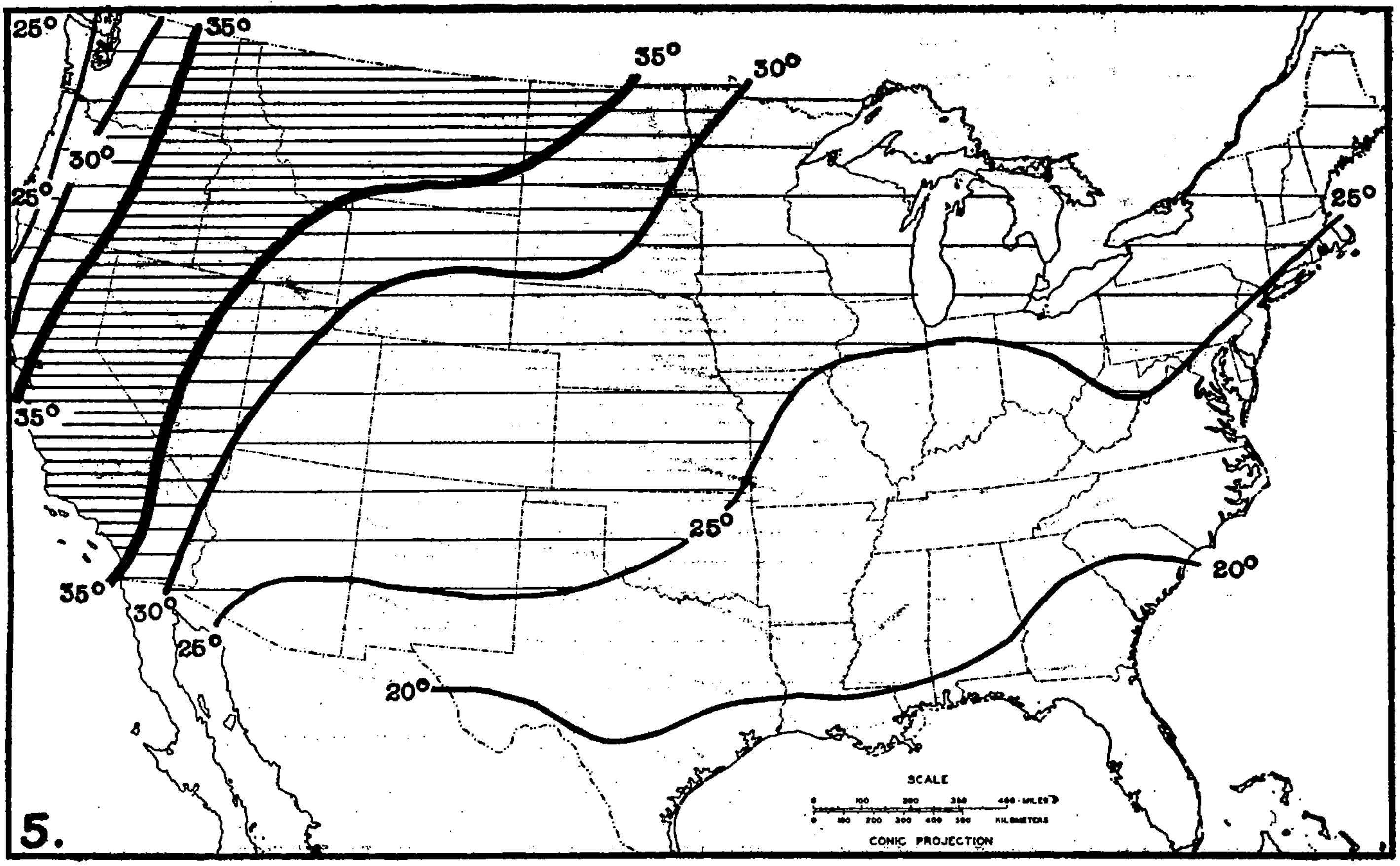

FIGURE 5.—Difference between July average temperature and mean annual maxima (° F.).

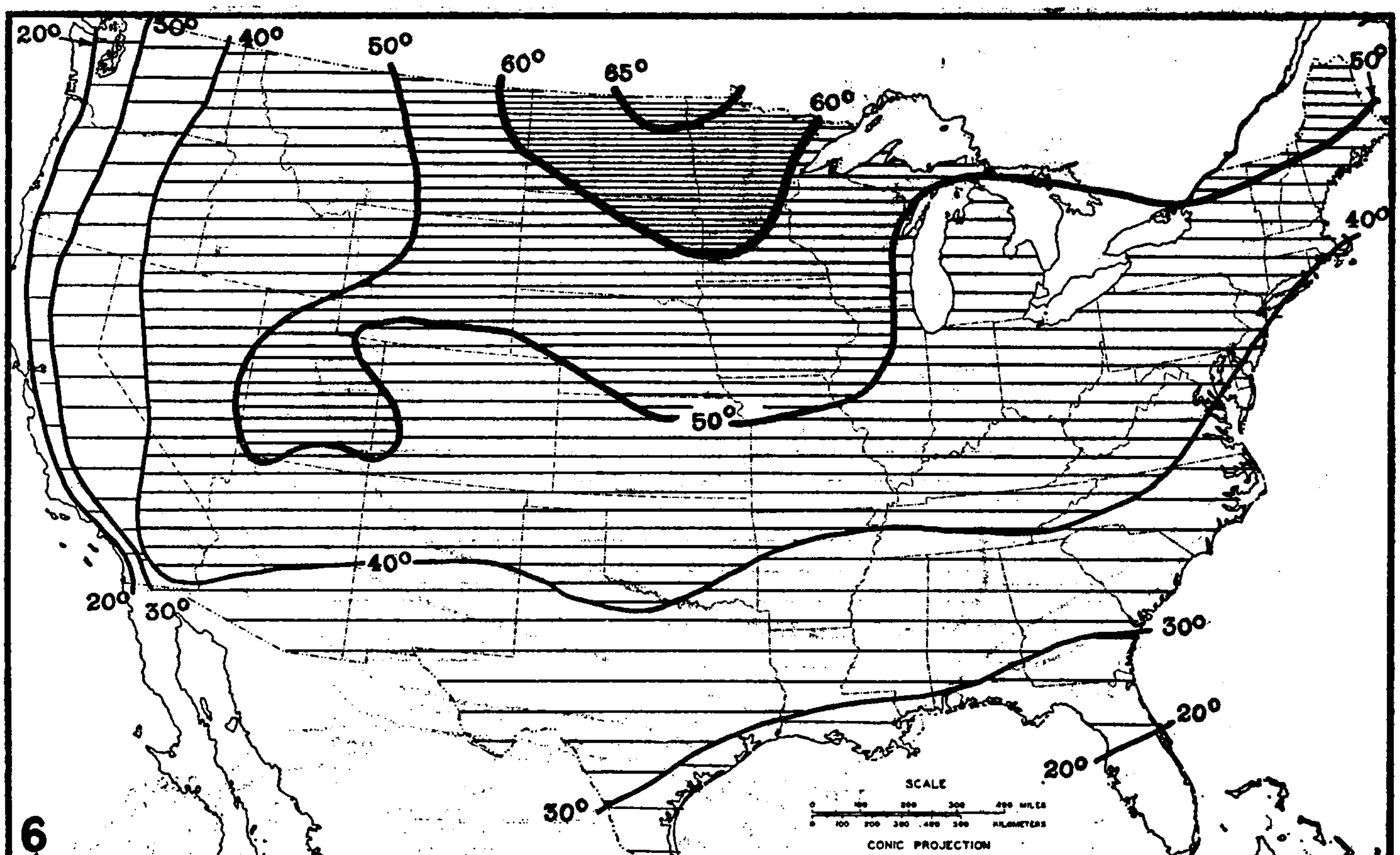

FIGURE 6.—Difference between mean January and mean July temperatures (° F.).

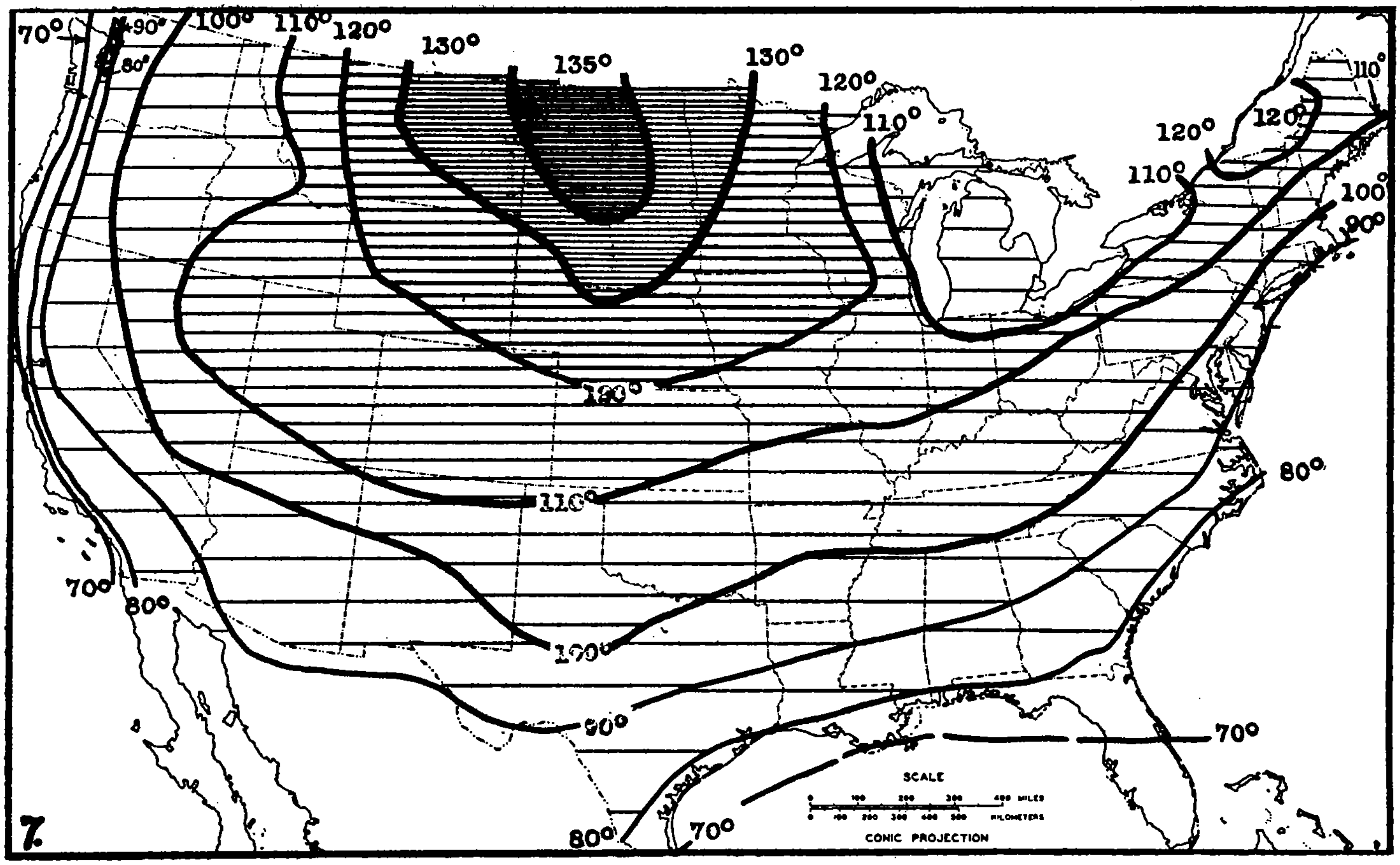

FIGURE 7.—Mean annual range (difference between average annual minima and maxima (° F.)).

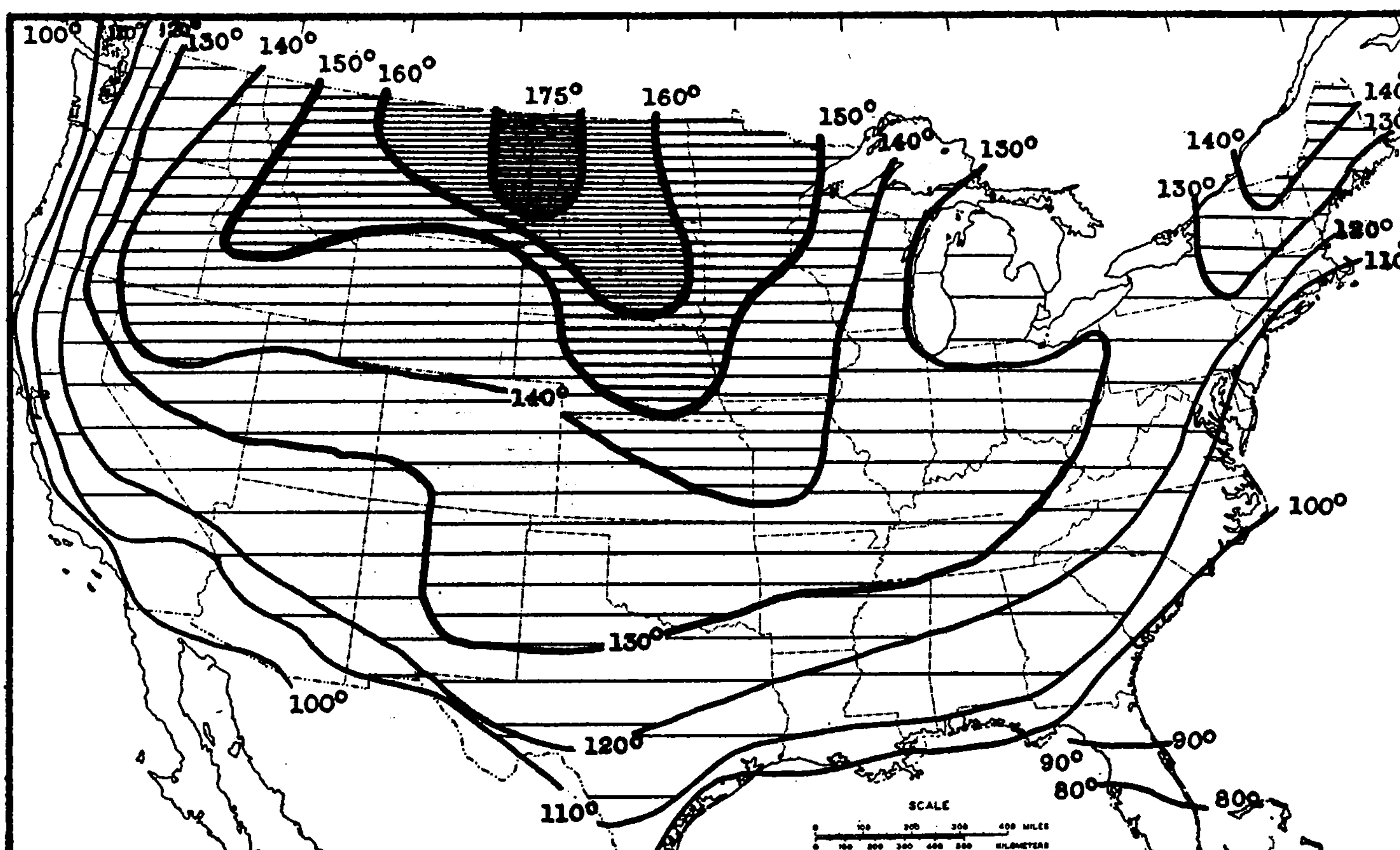

FIGURE 8.—Extreme range (difference between the lowest and the highest temperatures recorded in 40 years (° F.)).

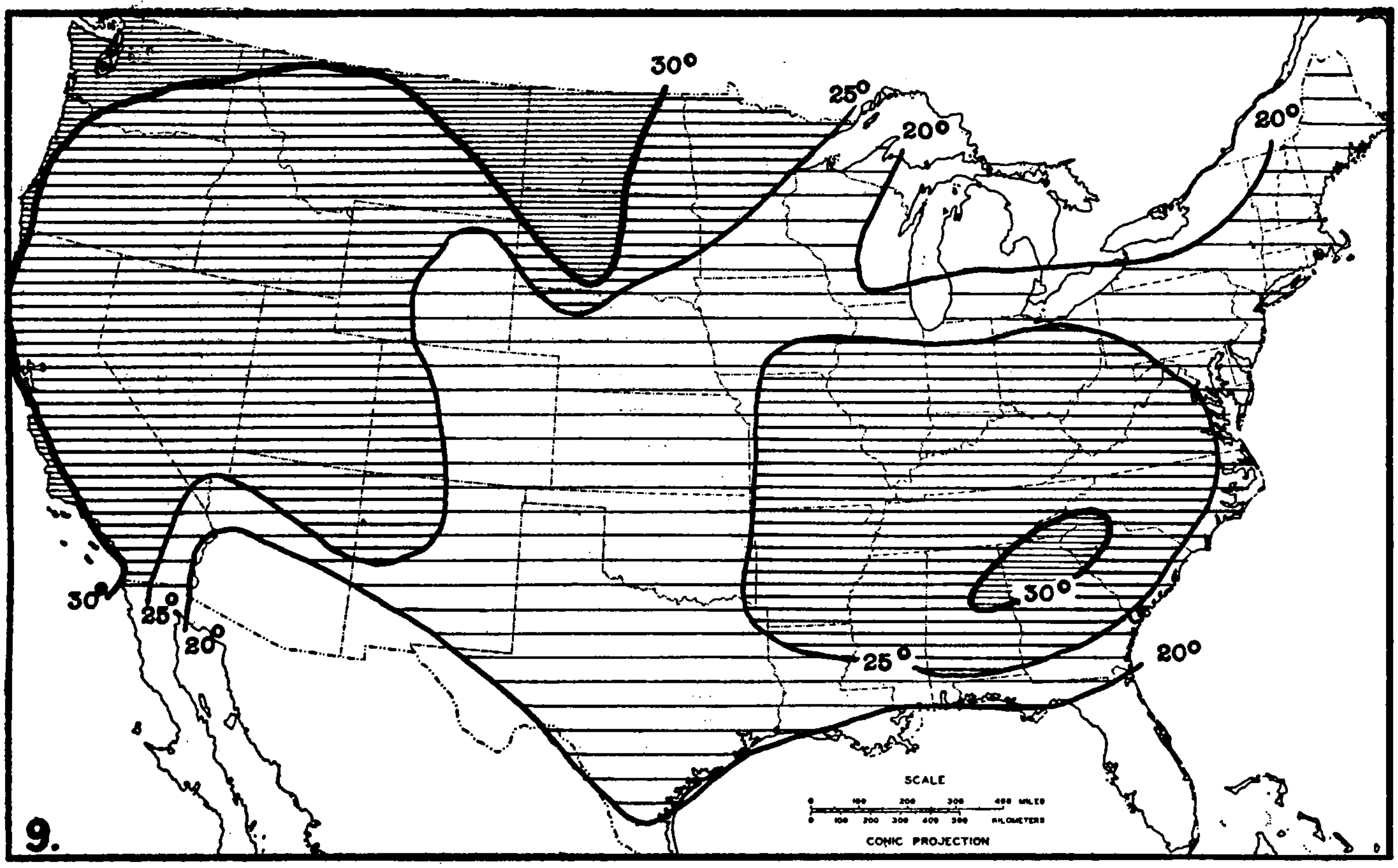

FIGURE 9.—Spread between annual or normal temperature range and extreme range (° F.).)

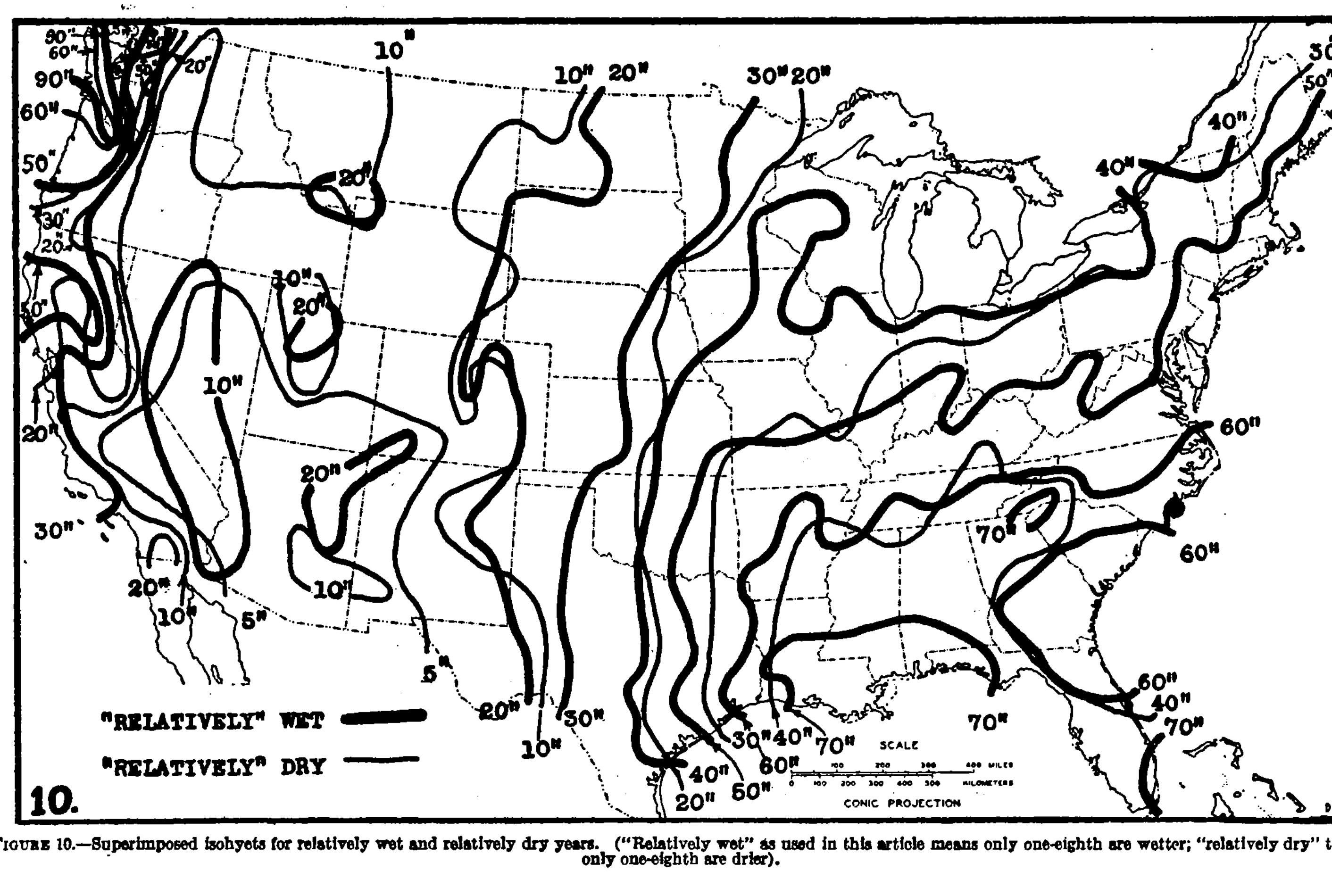

FIGURE 10.—Superimposed isohyets for relatively wet and relatively dry years. ("Relatively wet" as used in this article means only one-eighth are wetter; "relatively dry" that only one-eighth are drier).

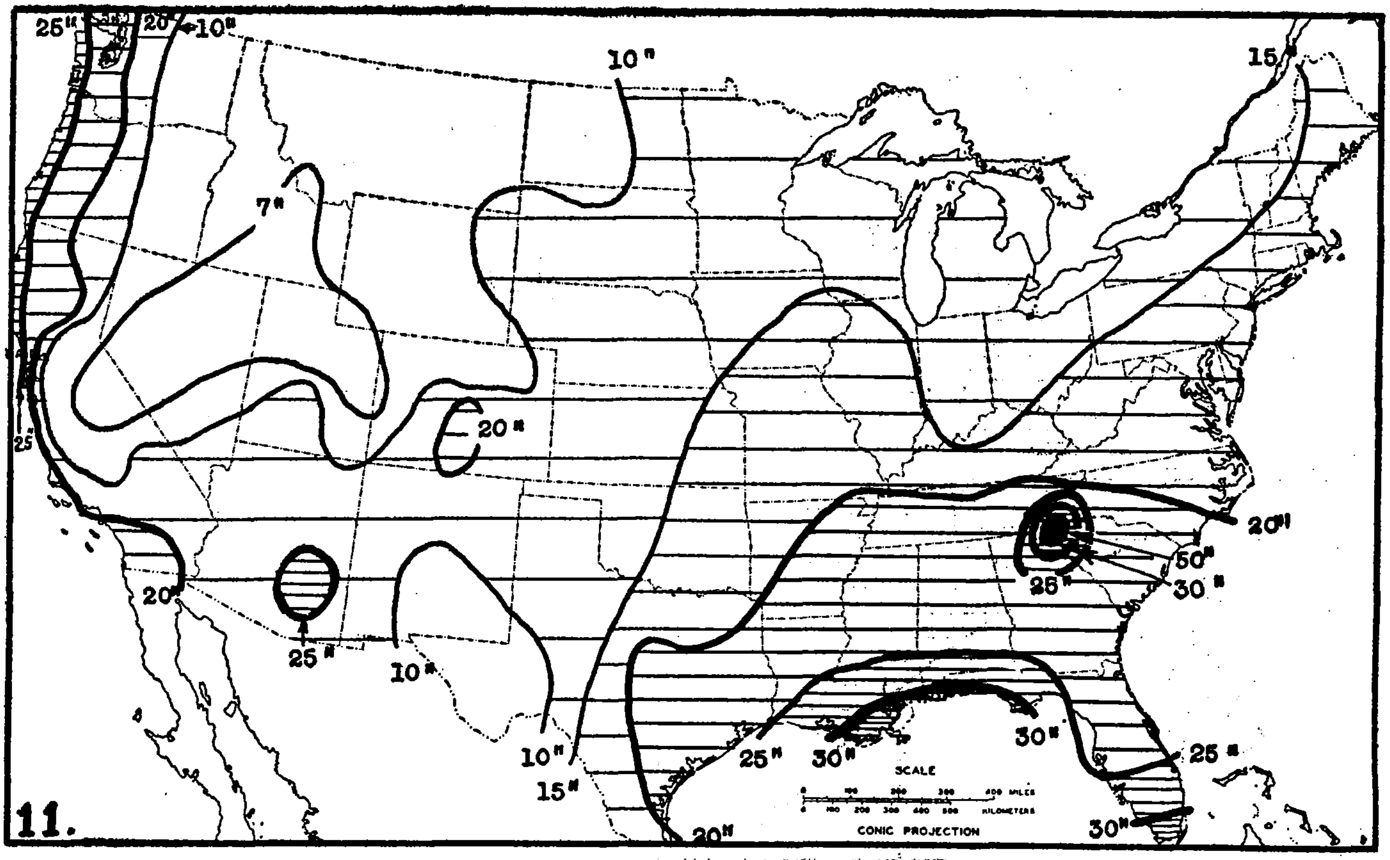

FIGURE 11.—Precipitation contrasts between relatively wet and relatively dry years (inches).

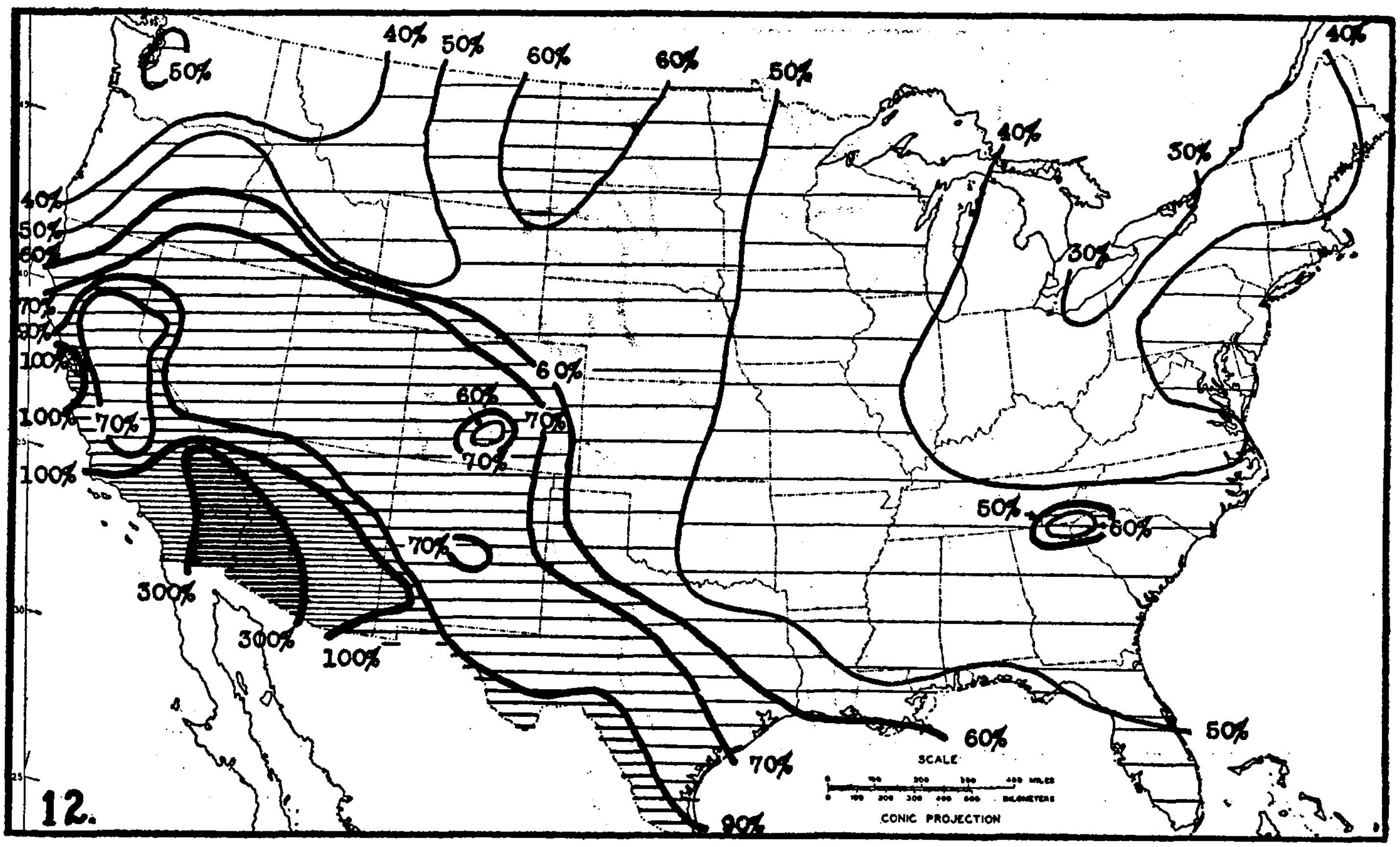

FIGURE 12.—Percentage variation between relatively wet and relatively dry years. (In ¾ of the years the departure from normal is less than the percentage here indicated).

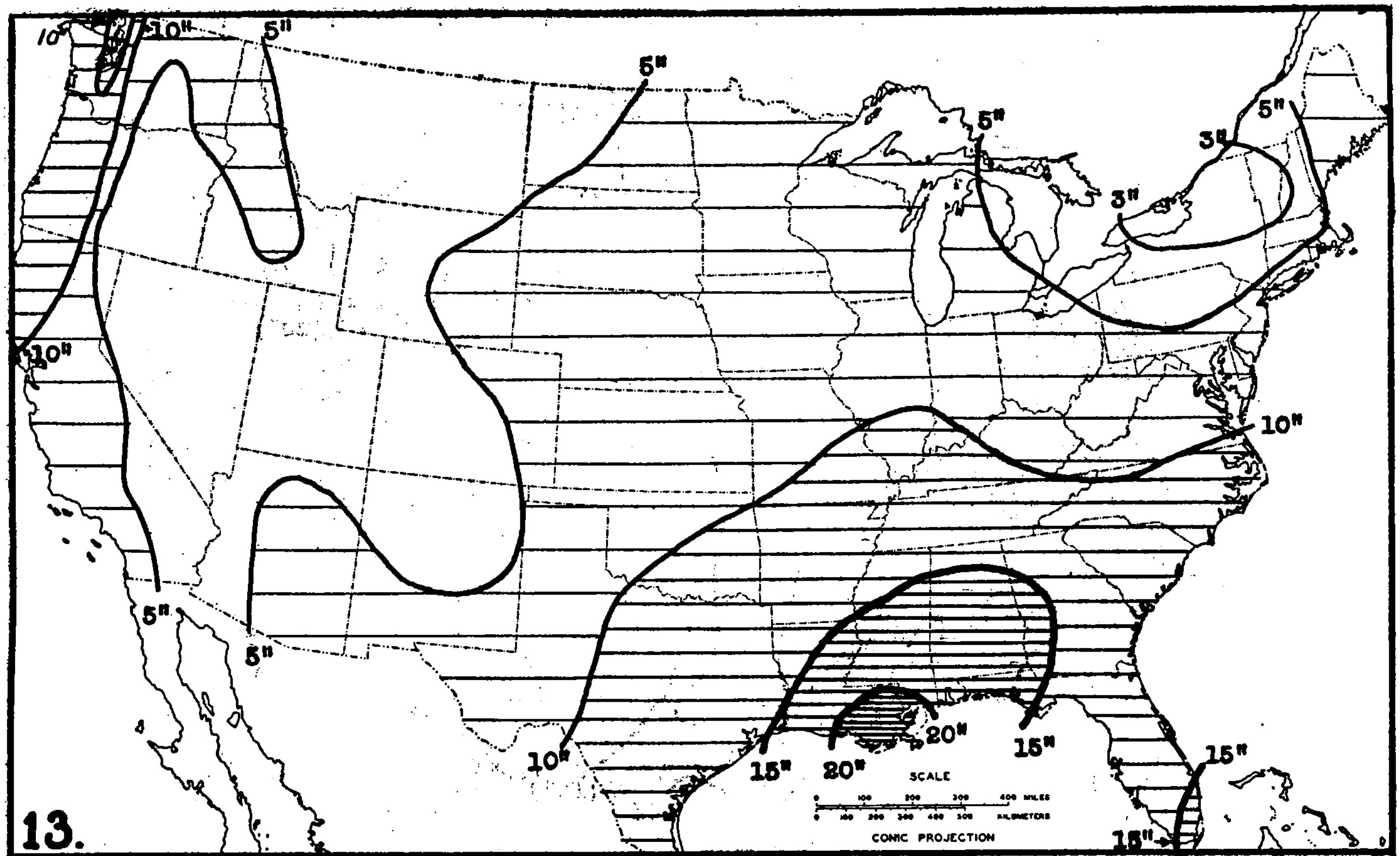

FIGURE 13.—Increased precipitation of a relatively wet over normal month (inches).

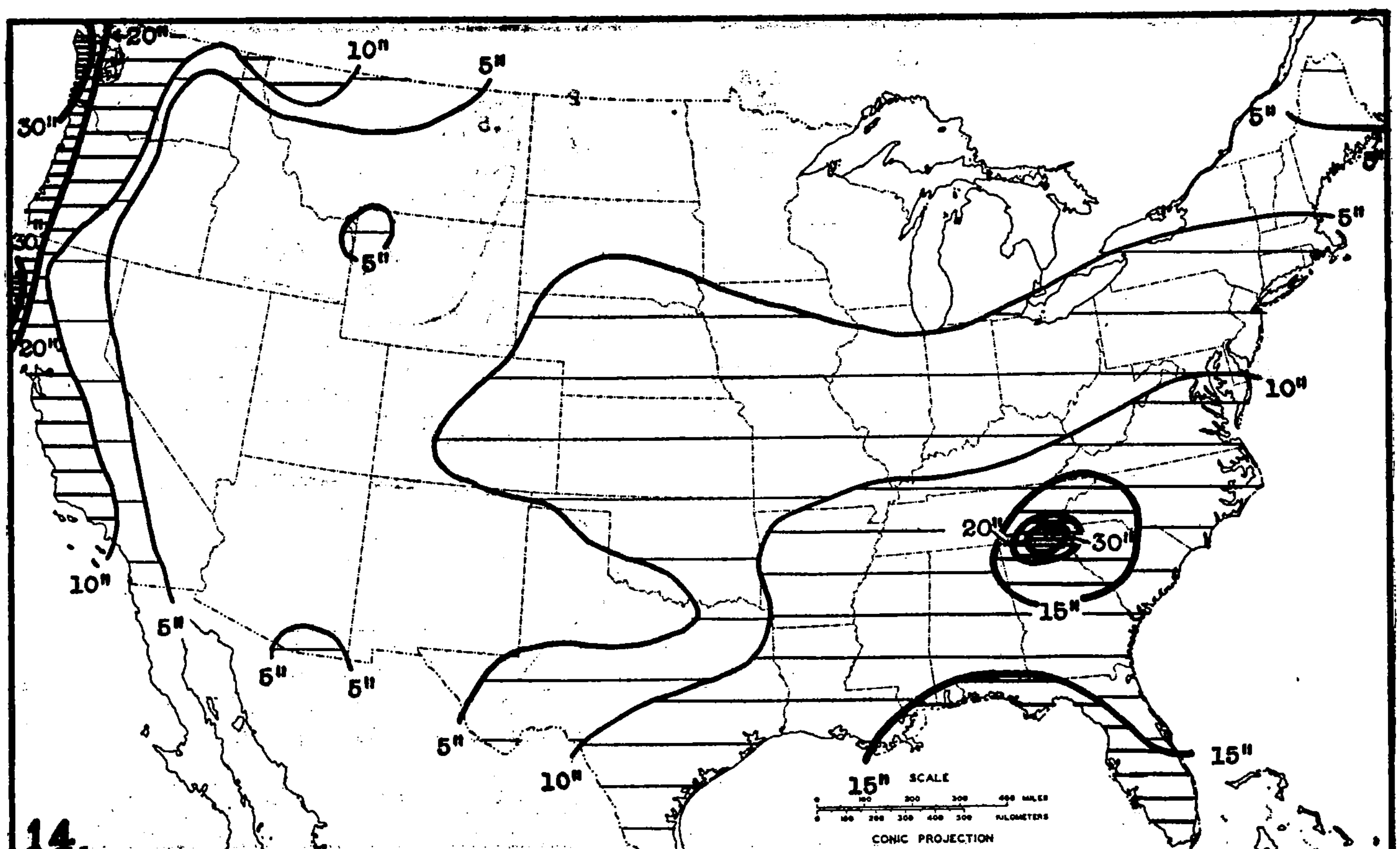

FIGURE 14.—Decreased precipitation of a relatively dry year as compared with normal (inches).

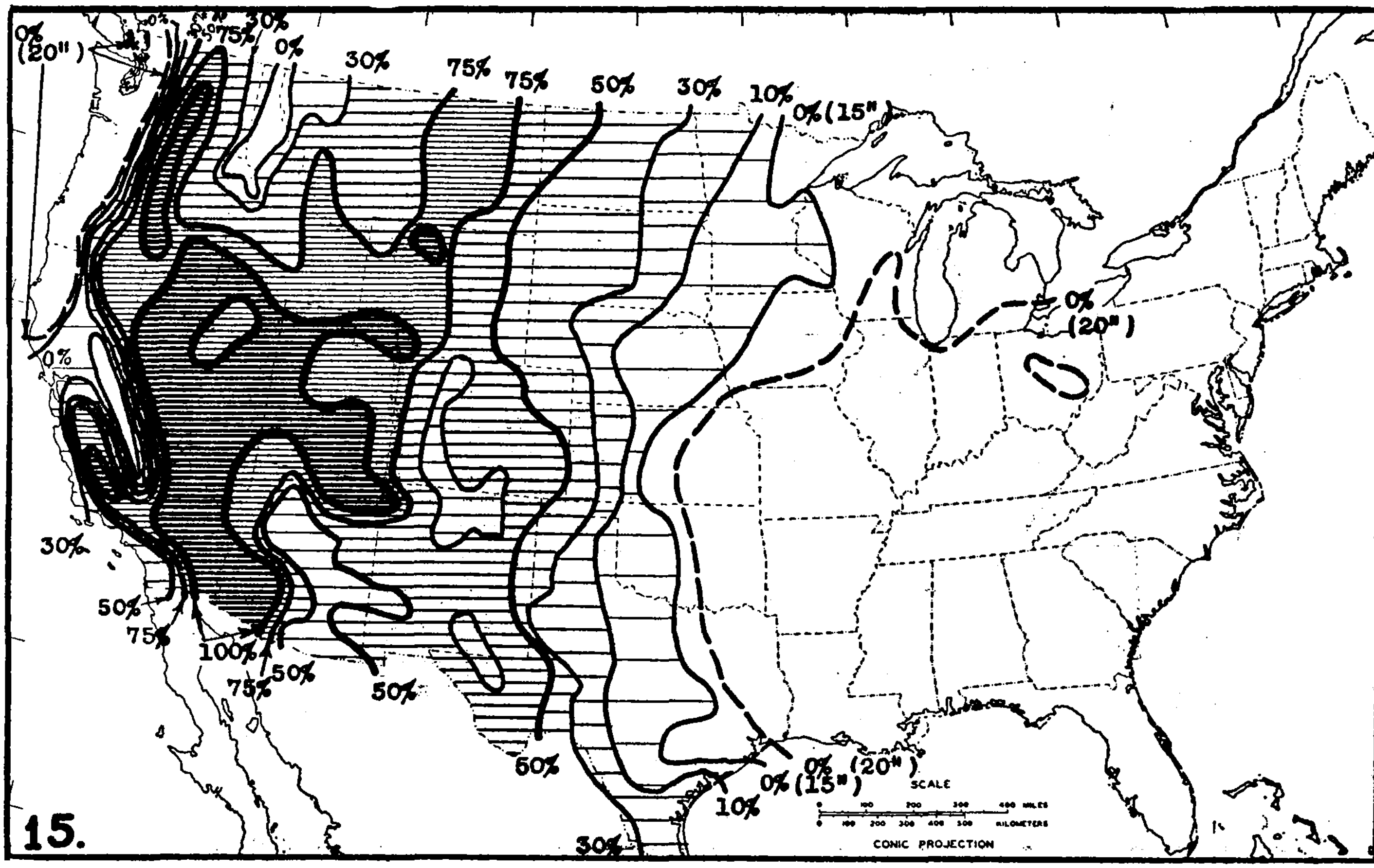

FIGURE 15.—Percent of years having less than 15 inches of precipitation. (Between the zero line and the dashed line, the driest years receive 15 to 20 inches).

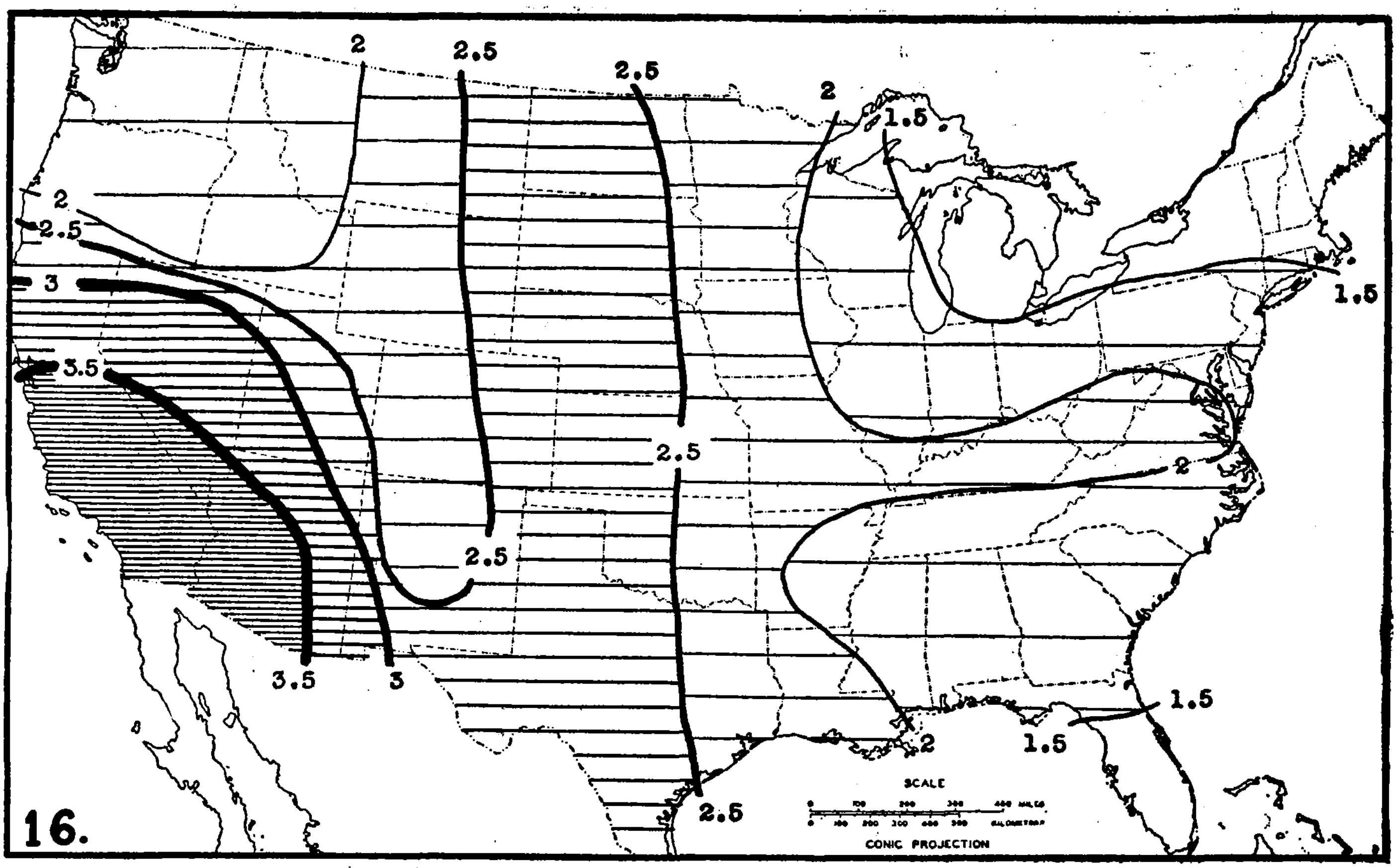

FIGURE 16.—Ratio between precipitation totals of wettest and driest years of a half century (1889-1938). Wettest year received indicated times as much as the driest. Based on State averages.

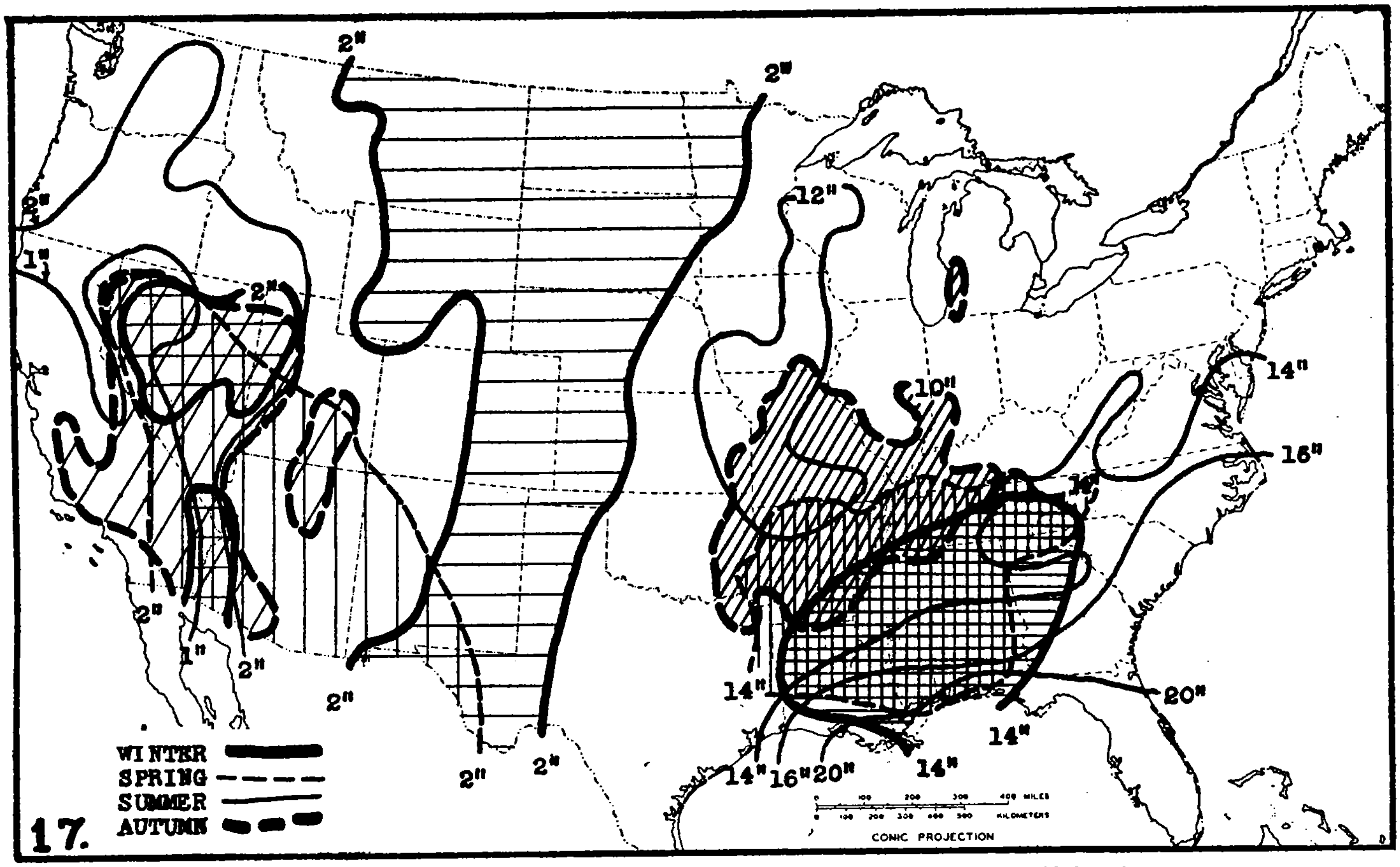

FIGURE 17.—Areas of little and heavy precipitation, by seasons (superimposed selected seasonal isohyets.).

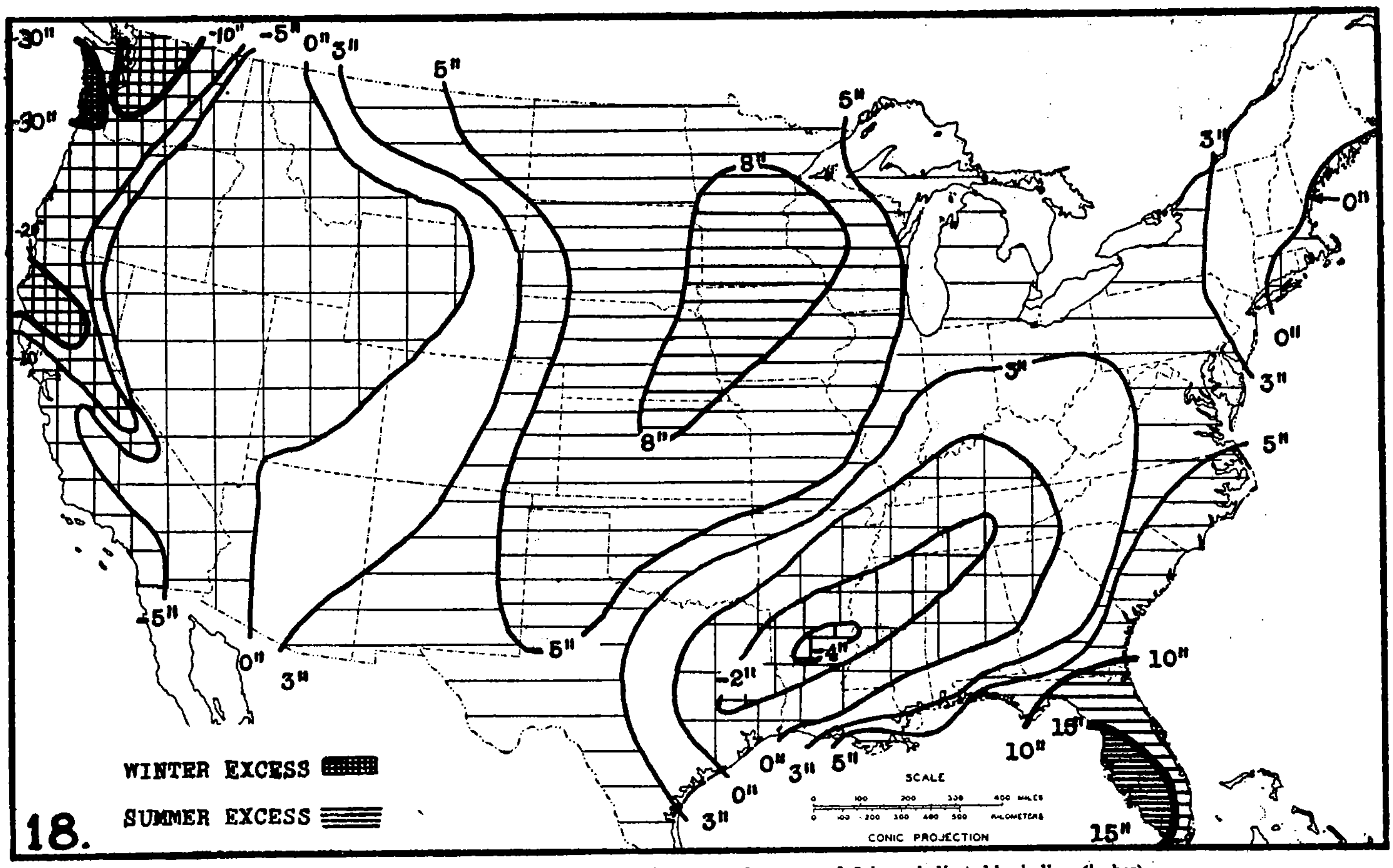

FIGURE 18.—Summer and winter precipitation totals contrasted; excess or deficiency indicated by isolines (inches).

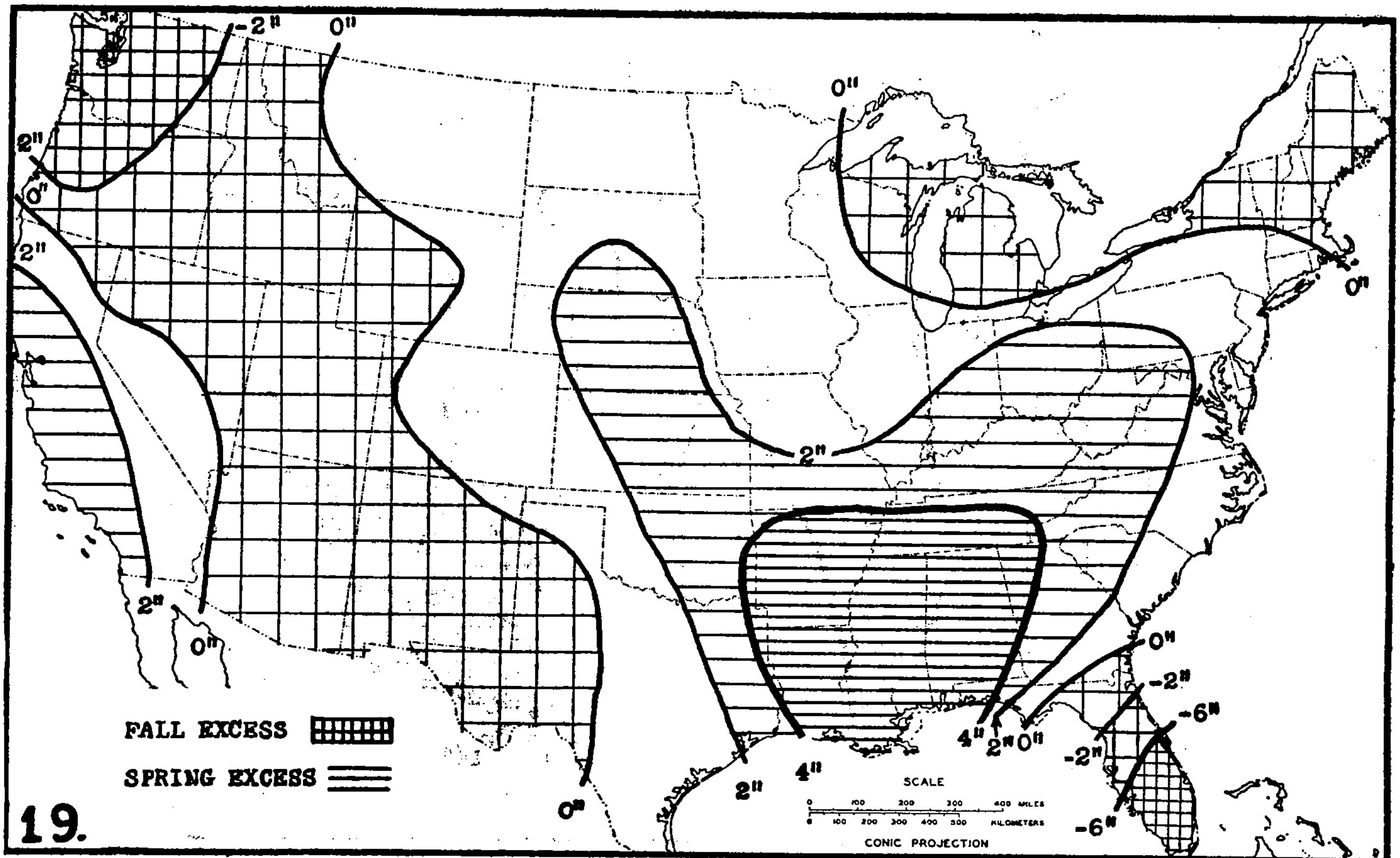

FIGURE 19.—Excess or deficiency of spring's precipitation as compared with autumn's (inches).

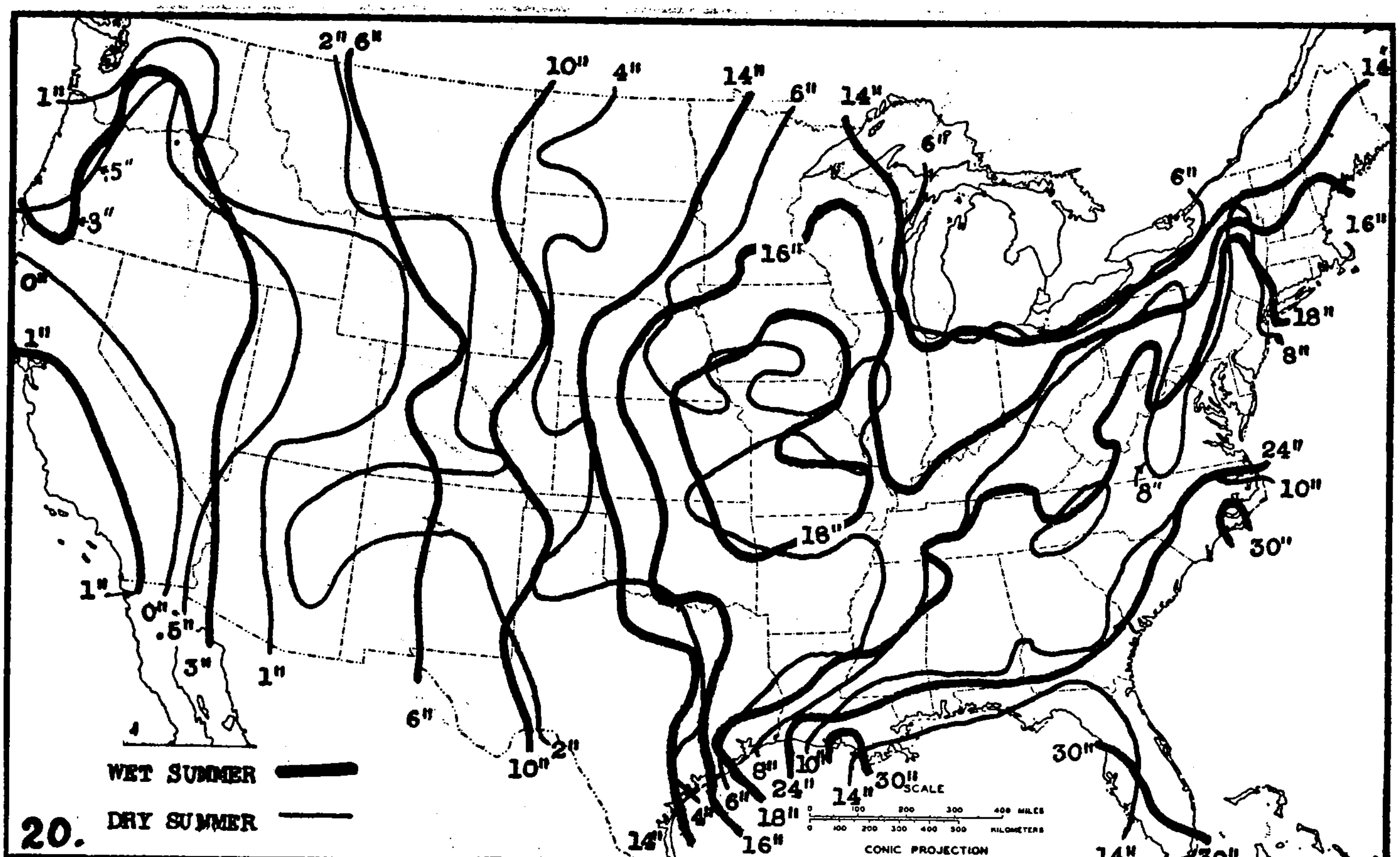

FIGURE 20.—Relatively wet and relatively dry summers, totals received (inches) shown by selected isohyets.

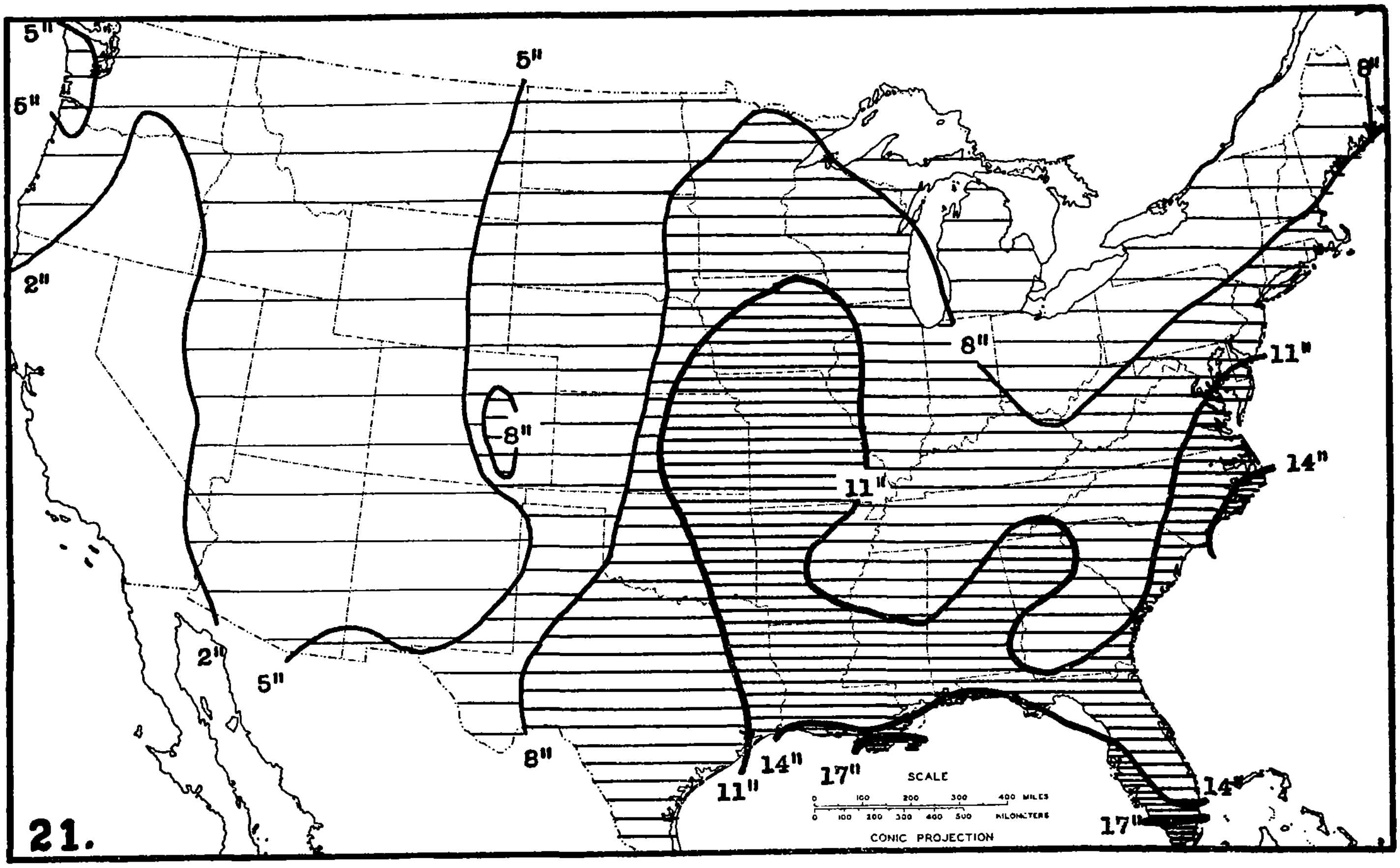

FIGURE 21.—Summer precipitation spread between relatively wet and relatively dry seasons (inches).

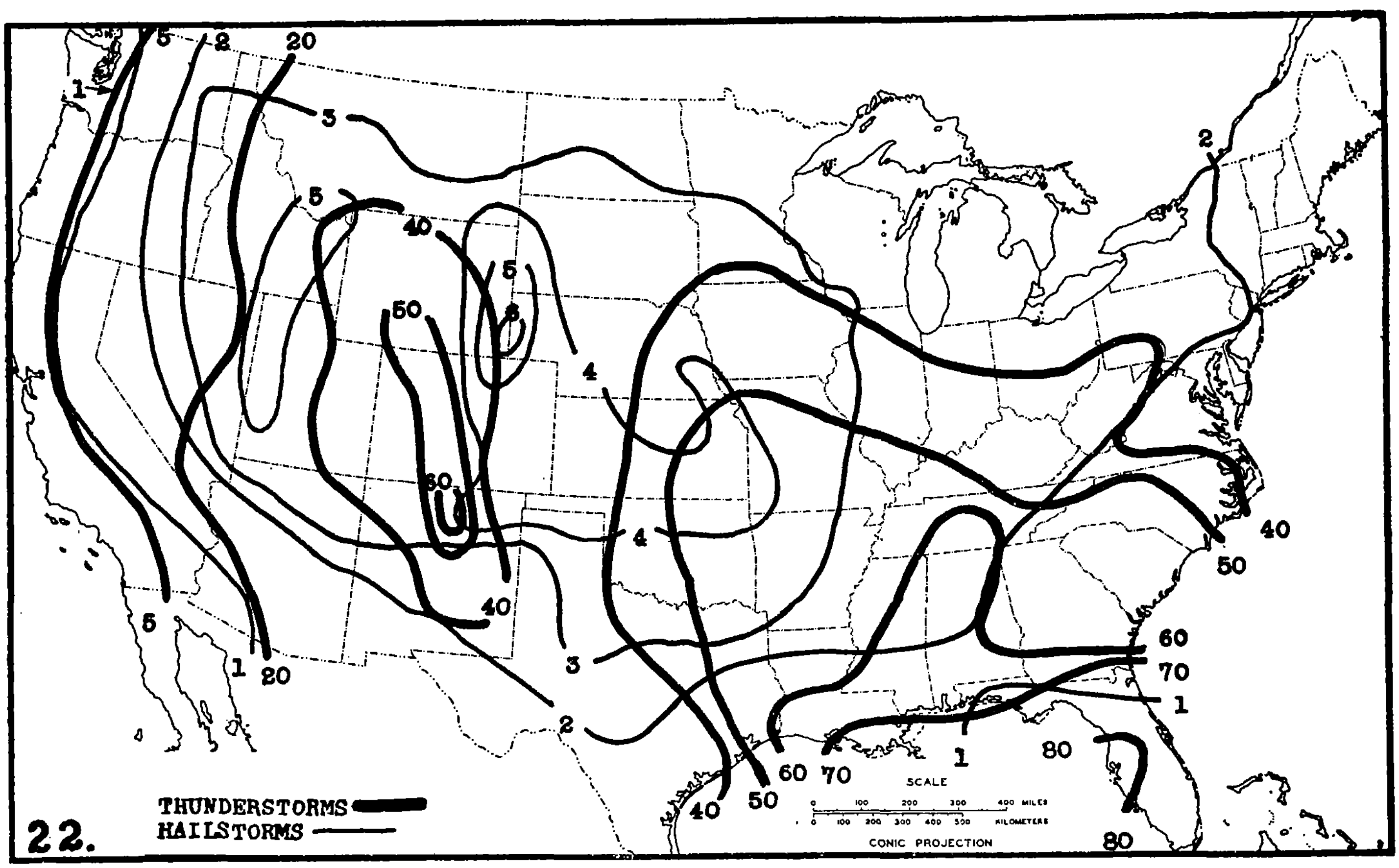

FIGURE 22.—Superimposed isolines showing the annual average number of thunderstorm days and of damaging hailstorms.